MEMO

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ENVIRONMENT

From:
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Date:
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ARCADIS Project No.:
30006877

Subject:
Response to EPA Questions issued on Jan 16, 2020

In response to a set of questions from the United States Environmental Protection Agency (USEPA), related to the risk assessment report submitted in October 2019[1] as support to the petition for beneficial use of phosphogypsum, Arcadis has prepared the following responses and comments.

For each paragraph provided by EPA in their questions, Arcadis has provided a response. Where a full response could not be included in this memo, reference to additional information is provided.

Modeling approach:

1. USEPA: The developers of the risk assessment chose to use a deterministic (vs. stochastic) model using discrete input parameters judged to be typical. From the standpoint of model development, this was a simpler—and potentially clearer—approach. However, a probabilistic approach to model input parameters could have provided the opportunity to incorporate uncertainty and variability into the model, and also could have explicitly included other road designs or variations on road design.

Arcadis: Arcadis intentionally chose a deterministic approach as a full probabilistic approach is quite challenging to present to the public. We recognize that there are variations in scenarios and assumptions and therefore, we intentionally made assumptions and selected parameters that in our view overestimate the potential exposures and doses bracketing the risk. Moreover, the models are linear for key parameters, such as Ra-226 concentration and exposure duration and hence readily scalable. In addition, we believe that the current approach estimates a reasonable maximum exposure (RME).

The RME scenario considers the highest exposure that might reasonably be expected to occur, one that is well above the average case of exposure but within the range of possibility and is intended to provide the basis for estimating the maximum individual risk (MIR). Use of the RME to model baseline human health risks is a conservative approach, in that it yields upper-bound cancer risk and non-cancer hazard estimates (USEPA, 1989). The "intent of the RME is to estimate a conservative exposure case (i.e., well

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[1] Arcadis 2019. *Radiological Risk Assessment in Support of Petition for Beneficial Use of Phosphogypsum*, Report to The Fertilizer Institute, October.

above the average case) that is still within the range of possible exposures."[2] Each exposure factor used to estimate the RME should be selected "so that the resulting estimate of exposure is consistent with the higher end of the range of plausible exposures" (citing EPA 1991 guidance).[3]

A National Academy of Science (NAS) Committee reviewing EPA's regulation of technologically enhanced naturally occurring radioactive material (TENORM) recommended that EPA "should use exposure and dose risk assessments that are "reasonably realistic"" in developing standards for exposure to the various types of low level naturally occurring radiation.[4] "The Committee defined "reasonably realistic" as "not … .intended to greatly overestimate or underestimate actual effects for the exposure situation of concern."" and EPA agreed with the Committee's recommendations.[5] The use of reasonable exposure assumptions is supported by the courts, which have long held that exposure assumptions used "must bear some rational relationship" to the actual conditions, and disallowed unduly conservative approaches.[6]

The current deterministic approach of the Risk Assessment focusing on RME scenarios to estimate MIR, provides the best alignment with the purpose of the RA, to compare predicted risks from the proposed use of PG against the risk threshold that is consistent with the determination of a 'safe' level. Overall, the choice of parameters other than those used in the current risk assessment are more likely than not to result in lower doses and risks to the receptor.

Probabilistic (stochastic) approaches would provide added information of the potential variability and uncertainty of the risk at lower risk levels, but overall would not change MIR substantially. In addition, the

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[2] EPA, EPA: Risk Assessment Guidance for Superfund: Volume III - Part A, Process for Conducting Probabilistic Risk Assessment, 7-1 (2001), *available at* https://www.epa.gov/sites/production/files/2015-09/documents/rags3adt_complete.pdf. See also Interstate Technology Regulatory Council, Decision Making at Contaminated Sites, Issues and Options in Human Health Risk Assessment at 6.1.1 (2015), *available at* https://www.itrcweb.org/risk-3/Default.htm#6.%20Exposure%20Assessment.htm#6.1__Determining_Appropriate_Exposure_Factors%3FTocPath%3D6.%2520Exposure%2520Assessment%7C6.1%2520%2520Determining%2520Appropriate%2520Exposure%2520Factors%2520%7C_____0 (ITRC, Decision Making at Contaminated Sites), citing EPA Guidance, which states that "[t]he RME . . . can be defined as "the maximum exposure that is reasonably expected to occur within a potentially exposed population."

[3] Id.

[4] EPA, Report to Congress, Evaluation of EPA's Guidelines for Exposures to Technologically Enhanced Naturally Occurring Radioactive Materials (TENORM), 15 (June 2000) (describing a National Academy of Sciences report on TENORM), available at https://www.epa.gov/sites/production/files/2015-04/documents/402-r-00-001.pdf (EPA Report to Congress Re: TENORM).

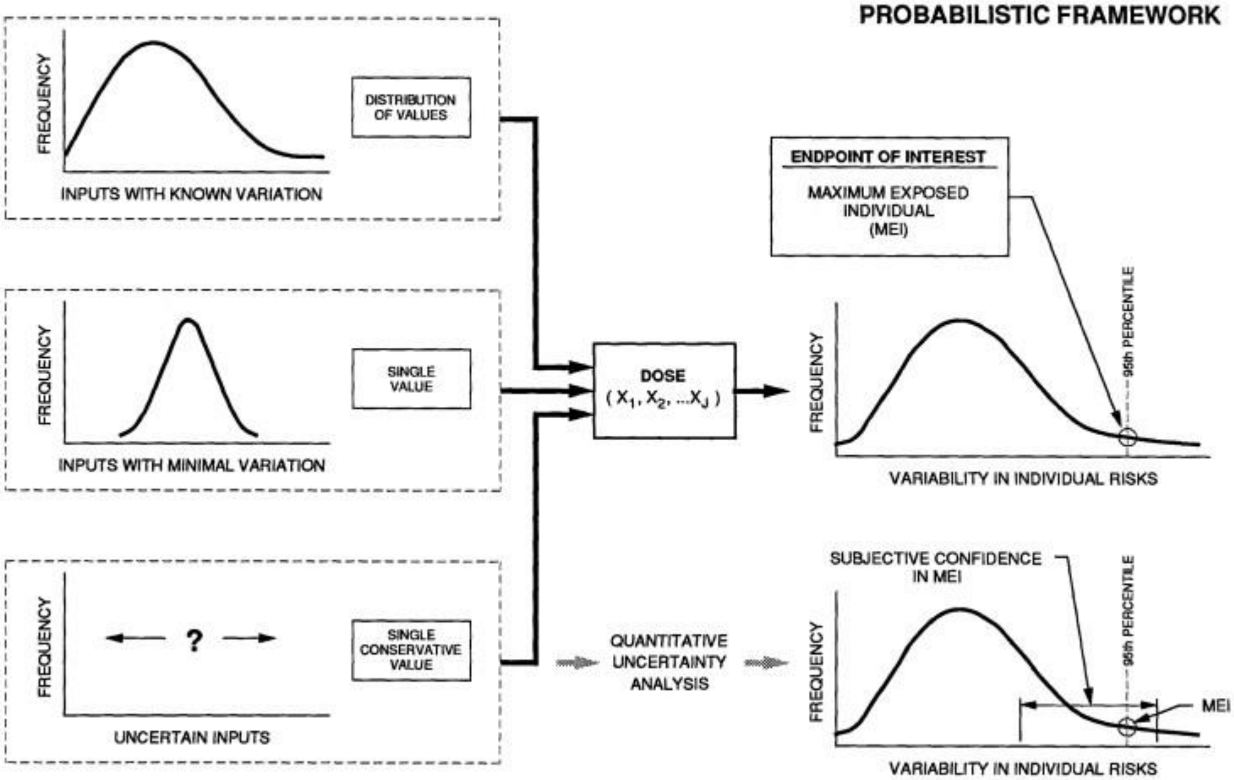
[5] Id.

[6] *Leather Indus. of America v. EPA*, 40 F.3d 392, 405 (D.C. Cir. 1994).

complexity of developing subjective probability distribution functions for the model parameters can be quite difficult and often challenging to explain to the general public and thus the probabilistic approach was not selected for the assessment. The modelling approach using deterministic parameters to calculate RME dose and risk estimates was reviewed with EPA in advance of the Risk Assessment.

To illustrate the possible output of a probabilistic approach Figure 1.1 is provided below. The deterministic approach targets calculations for the Maximum Exposed Individual (MEI) or person in the RME scenario, often someone at the upper-end (approximately 90th to 95th percentile) of dose (risk). EPA guidelines state that the assessor may derive a high-end estimate of exposure by using maximum or near maximum values for one or more sensitive exposure factors, leaving others at their mean value.[7] Based on our experience with regulatory decisions, the MIR from a deterministic assessment as performed in our October 2019 risk assessment would be generally comparable to these upper limits of dose (risk).

FIGURE 1.1
PROBABILISTIC FRAMEWORK



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[7] Exposure Factors Handbook: 2011 Edition at (2011) https://cfpub.epa.gov/ncea/risk/recordisplay.cfm?deid=236252.

2. USEPA: 61.206(b)(8) requires the risk assessment to include an estimate of the risk distribution.

Arcadis: The original NESHAPS (December 15, 1989 Federal Register) defines a risk distribution estimate as how many persons within a certain distance (e.g. 80 km) of a source of pollutant emissions are at an increased level of individual risk. This requires an estimate of the dispersion of a radioactive pollutant, from a source and an estimate of the population within that distance.

EPA clarified at our meeting that providing more risk distribution information was information on how the risk varied with the "variation of the geometry of exposure" and with different exposure time frames. The RME approach utilized in the risk assessment also 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.

Although risk distribution was used in 1989, many EPA risk assessments (including the 1992 BID risk assessment) do not utilize risk distribution. The general risk distribution discussed below is acceptable in this situation.

The radiological "pollutants" associated with PG in roads are direct gamma emissions, particulates, and radon. As shown in the risk assessment, external gamma is by far the dominant source of dose, followed by radioactive particulate emissions and radon.

The gamma exposure dose decreases rapidly with distance, for example at one road used in a Florida Institute of Phosphate Research (FIPR) study, the exposure was indistinguishable from background levels at 50 feet from the road centerline (FIPR, 1989[8]). For the nearby residential exposure scenario, the risk calculated in the October 2019 radiological risk assessment calculated that radiological exposure is always below background levels and reduces with distance from the road, becoming indistinguishable from the variability of background at 50 feet from the road's edge.

Background terrestrial radiation has been shown to have wide variability between states and within states in the US (S. Cohen & Associates 2005)[9].

> *It is instructive to note that not only are there substantially large differences in the average terrestrial doses among states (e.g., 14.3 mrem/yr in Florida versus 42.6 in Colorado), but there are also large differences in the average terrestrial dose rates among cities within a state. For example, in Colorado, the average terrestrial dose rate in Pueblo is 29.2 mrem/yr, while in Denver it is 57.4 mrem/yr. In Las Vegas, Nevada, the terrestrial dose rate is 12.7 mrem/yr, while in non-urban regions of Nevada it is 29.2 mrem/yr.*

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[8] Chang, Wen F., Chin, David A., and Ho, Robert, 1989. Phosphogypsum For Secondary Road Construction, University of Miami, For Florida Institute of Phosphate Research, Publication No. 01-033-077, 01-041-077.

[9] S. Cohen & Associates. 2005. Assessment of Variations in Radiation Exposure in the United States Contract Number EP-D-05-002 Work Assignment No. 1-03. Prepared for U.S. Environmental Protection Agency Office of Radiation and Indoor Air 1310 L Street, N.W. Washington, DC 20005.

The USNRP in Report No. 160[10] confirms the range of background terrestrial radiation dose in the USA is variable, depending on local geology and other factors, and ranges from about 10 mrem/y to more than about 40 mrem/y.

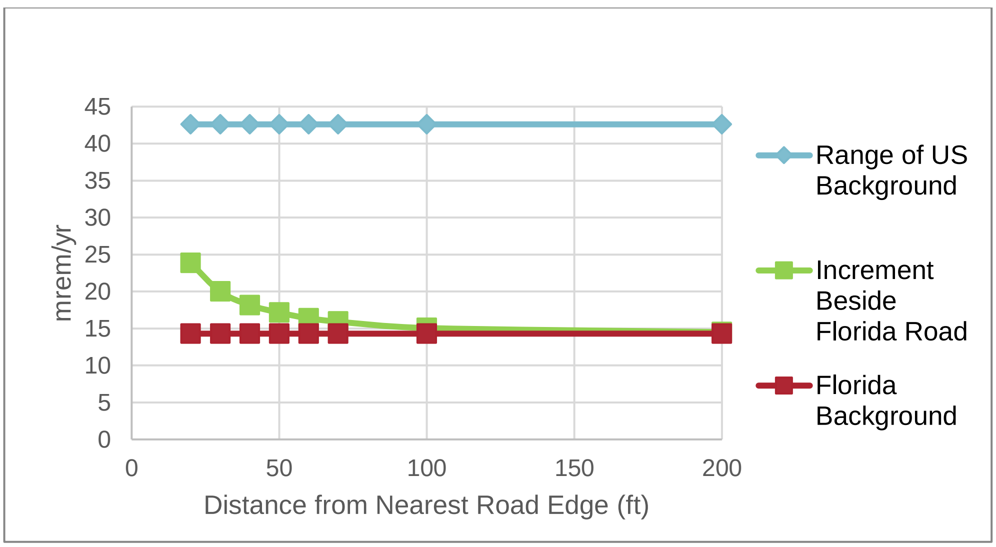
Figure 2 below combines the (notional) background radiation dose in Florida with the incremental dose from a PG road. The figure also displays the upper range of background radiation dose in the US (for Colorado). This clearly shows that dose from a PG road is inconsequential relative to background for distances typical for the closest residence. Further it shows that at distances reasonable for a second closest residence (approximately 100 feet) the dose is essentially zero.

These distances are well short of the 80 km values used in the 1989 risk distribution. Therefore, the contribution to a risk distribution is zero beyond that distance.

Similarly, it was shown in the Risk Assessment that the dose from inhalation and ingestion of particulates was also quite low, less than 10% of the total dose for the worker in the center of the road. As particulate concentration is highest on the road in the construction zone, particulate concentrations reduce with distance from the road and will quickly reach background levels again resulting in zero dose contribution to the risk distribution. In addition, particulate generation is only relevant during construction which occurs for a limited duration in any one location.

Last, is the radon generated from the road. Outdoor radon is quickly disbursed to background levels within a few tens of feet from the road, see for example the measurements on roads constructed with PG. (FIPR, 1989, “Phosphogypsum for Secondary Road Construction”). As previous, the calculated contribution to the risk distribution from radon is zero.

Figure 1 – Incremental External Gamma Dose with Distance Compared to Terrestrial Background



[10] NCRP Report No. 160, Ionizing Radiation Exposure of the Population of the United States

The following table provides summary comments on risk distributions by exposure pathway. The table explains the limited applicability of the RME scenario and the potential for lower exposures and doses to occur for a broader population.

SUMMARY OF RISK DISTRIBUTION FROM USE OF PG IN ROAD CONSTRUCTION		
Exposure Scenarios	RME (small number of people)	Potential Lower Exposures and Risk Distribution
Road Construction Worker	Risk: 0.5 in 10,000 Few if any workers would fit the RME assumption of 100% of workdays on the uncovered road base. The RME worker is exposed to less than 7% of background levels (for all members of the public.	Much less than 0.5 in 10,000 Most workers are expected to spend less than 100% of the workday on the uncovered road base. Dose and risk reduce linearly with reduced exposure time. Time on a covered road base was shown in the Risk Assessment to be a factor of 5 lower. The dose would range down to essentially zero for management and supervision who would spend very limited time on the road and out of vehicles. The number of workers in a road crew is estimated to be as small as 6 – 8 workers, which limits the risk distribution to a small group.
Road User	Risk: 0.1 in 10,000 This RME is assumed to be a heavy user of the road spending 2 hours daily on the road. This scenario is unlikely to occur until far into the future if PG roads become widely available. Until then it is unlikely a commuter would be able to spend this amount of time on a PG road. In the extreme case, the RME road user is exposed to less than 0.3% of background.	Well below 0.1 in 10,000 Most road users will be on the road for much less than two hours per day. Dose and risk reduce linearly with reduced exposure time. Initially when PG use in roads is newly implemented the availability of PG roads will be low reducing the opportunity to have substantive usage time. As the total amount of PG roads increase the risk distribution would increase with additional road users and cumulative usage time. The overall risk to an individual however, is not expected to exceed the RME estimates. Most road users would still have limited time on PG roads and this results in a proportionally limited dose and risk. The overall number of road users is difficult to specify as it depends on several factors including

		the road type and location relative to populated areas. However, the dose to road users would remain a small fraction of that from unavoidable background radiation.
Truck Driver	Risk: 0.5 in 10,000 The Truck Driver RME is limited to workers who participate in PG road construction projects. The assumptions for this scenario are set to estimate the upper end of likely dose and risk for this work. The RME Truck Driver is exposed to less than 6% of background levels.	A truck driver that has less than an RME exposure has lower risk than 0.5 in 10,000. There are a limited number of truck drivers involved in a road construction project. In addition, truck drivers will support numerous construction projects during the course of a year and many not involving use of PG. This limits the risk distribution for this exposure pathway to a relatively small number of people. In many cases, Truck Drivers will not work on PG road construction as much as assumed for the RME, resulting in a lower dose and risk.
Nearby Resident	Risk: 0.08 in 10,000 The Nearby Resident RME is based on extreme assumptions that are unlikely to apply to all residents of a PG road. The assumptions include close exposure to the road and long durations of residency throughout the exposure period. Based on these assumptions the Nearby Resident RME is exposed to 0.2% of background levels.	Most residents near a PG road would be exposed to much lower doses and risk, well below 0.08 in 10,000. Radiation levels from a PG road decrease rapidly with distance from the road and become indistinguishable from background at 50' to 100'. See figure and discussion. As a result, most residents immediately beside a PG road would be exposed to much less than the RME risk level, and residents beyond the immediately adjacent properties would experience essentially zero incremental risk. The overall risk distribution would depend on the overall length of the PG road and population density along the road but is limited to only those locations immediately beside the PG road.
Utility Worker	Risk: 0.004 in 10,000 The Utility Worker RME scenario represents an extreme case where a worker needs to disrupt the road for road or utility maintenance. The assumptions use worst case conditions to estimate the risks	Most Utility Workers would be exposed to risk much less than 0.004 in 10,000. Most utility repair requirements would involve exposure scenarios below those assumed for the RME conditions, due to smaller trenches and exposure areas, or shorter durations.

	and are limited to workers in a trench in a PG road and meeting the other exposure assumptions. The RME Utility Worker is exposed to approximately 0.3% of background levels.	The number of individuals entering a trench in a PG road is also limited based on the uniqueness of the work and the limited space. As a result, the risk distribution for the Utility Worker is limited to a small number of individuals.
Reclaimer Extreme Scenario	Reclaimer is an extreme scenario well beyond an RME assumption and therefore, is not appropriate to determine whether the use of PG is safe. This example for ultimate disposal was selected due to the use by EPA in 1992. Risk: 0.4 in 10,000 The Reclaimer would be exposed to approximately 1% of background levels. (total exposure of 78 mrem compared to a Background of 8,060 mrem over 26 years)	The Reclaimer scenario represents an extreme situation that is unlikely to even occur as described. As a result, the risk distribution is effectively zero. More realistic situations for the ultimate disposal of the road include continued use of the road as a road, or reuse of the PG road base for a new road, if the road was to be relocated or realigned. In the extreme case where a road is abandoned and then the land is reused for other purposes, the land preparation activities will realistically result in blending and mixing of the road base to levels that are indistinguishable from background levels. Overall, the risk distribution would be effectively zero.

In summary, the risk distribution from road construction is negligible, beyond the individuals who are on or immediately beside the road, as assessed in the Risk Assessment document.

3. USEPA: No discussion of uncertainty in model outputs is provided. There is no discussion of uncertainty around model input parameters, with the minor exception of uncertainty of the dose-to-risk conversion factor (p. 1-1). Except for briefly mentioning variability in naturally-occurring background radiation (p. 3-4), the risk assessment does not address variability around model parameters such as exposure factors, activity concentrations, exposure duration, etc.

Arcadis: The Risk Assessment was developed to examine a conceptual road design, to provide an estimate of the upper end RME risks associated with PG use in roads. It is impractical to perform a risk assessment that uses different values for every conceivable road design. Neither the 1989 nor the 1992 BID risk assessment considered every conceivable road design. Many features (such as the number lanes) do not affect the potential exposure. Many other road design features were set at an upper bound RME value and any design that uses different value will reduce the risk or not be an RME.

The following is an example list of factors utilized to minimize the impact of any uncertainties.

- We assumed that EPA's 1992 BID risk assessment used high end assumptions as was the policy at the time. In general, the 2019 radiological risk assessment is more conservative (i.e., results in higher exposures) than the 1992 BID. The 2019 radiological risk assessment used the same exposure scenarios plus two new exposure scenarios.

- In conjunction with the submission of the Petition, TFI members agreed to perform radiological testing of PG. Nine PG stacks located in Central Florida (where the highest Ra-226 levels would be expected), Louisiana, and the Western U.S. with ten samples taken from each stack, for a total of 90 samples.4 A summary of the results is as follows:
  - The average Ra-226 concentration of all 90 samples is 18.6 pCi/g.
  - Ra-226 concentrations in individual samples range from 6.3 pCi/g to 27.9 pCi/g.
  - The average Ra-226 concentration from the 2019 stack sampling (18.6 pCi/g) is below the radioactivity concentration limit of 35 pCi/g proposed in the Petition, and well below the average Ra-226 concentration of 148 pCi/g that corresponds to an EPA safe risk level of 3 in 10,000.
  - No individual concentration from the 2019 stack sampling (with concentrations ranging from 6.32 pCi/g to 27.9 pCi/g) exceeds 35 pCi/g.
- The EPA 1992 BID assumed a 1:2 dilution of PG with soils for a road base concentration of 10 pCi/g. The October 2019 risk assessment utilized less dilution (1:1 PG:soil).
- The EPA 1992 BID assumed the road base was 0.25 m thick and 30 feet (9.15m) wide and that the road base is covered with a 0.12 m (5 in) thickness of asphalt. The October 2019 risk assessment utilized a road thickness of 0.25 m (the same as in 1992).
- The EPA 1992 BID assumed PG in a concrete road incorporates 15% PG by weight and 0.12 m thick (5 in) and 24 feet wide (7.32 m). The October 2019 reviewed road base design criteria and concluded 15% was a high-end criterion.
- The EPA 1992 BID used exposure to the critical population group member (nearby resident 100 m (i.e., 328 ft) from the edge of the road). The October 2019 radiological risk assessment calculates the radiation levels at 50 feet from the edge of the road.
- The current risk assessment assumes a worker moves around over the road surface and is exposed at the average of the gamma fields at the center and edge of the road, which is more reasonable than assuming a worker never moves for 5 years. The stationary worker is not realistic or reasonable, therefore it is not an RME.
- The 1992 EPA risk assessment used a 0.6 shielding for the road user, but rather than determine the degree to which vehicles have changed the amount of metal in the under carriage of cars, the current risk assessment takes no credit for shielding provided by the vehicle which however would provide some level of shielding which is a conservative assumption and could reasonably be considered.
- The current risk assessment considered two receptors beyond those considered in the 1992 BID (truck driver and utility worker).

Given the fact that each of the exposure assumptions are RME (including road design parameters), the uncertainty is addressed with the risk assessment without having to perform numerous risk calculations that will simply confirm the nature of the RMEs utilized. If EPA identifies any road design factors that increase the radiological risk and are RME, the Petitioners will evaluate it. In summary, as described in the first item under Modelling Approach above, the selection of deterministic parameters was done at the conservative end of the expected range of uncertainty, to provide calculations tending to overestimate expected results.

Conceptual road model:

4. USEPA: What is the generic composition (in more detail) of a road? For example, if road base is to be composed of a mixture of soil and PG, what are the ranges of composition of the soils to be used (e.g., organic carbon content, clay contents, moisture).

Arcadis: The Risk Assessment is intended to provide a conceptual exposure model of PG use in roads and is not linked to a specific road segment approval.

The selected example road was a four-lane county road with two lanes in each direction. This type of road is common in rural, suburban and urban settings and represents the type likely to be constructed by state and local governments who can employ PG during construction.

Choice of this road type permits evaluation of construction workers, nearby residents, bicyclists and motorists, and utility workers. The road dimensions are 15 m wide (about 12 feet [ft] per lane) and 100 m long (segment length) for modelling exposures. The thickness of the road base containing PG and road surface (i.e., pavement) are 0.25 m and 0.12 m respectively consistent with the EPA BID (1992).

The road base in the example road was selected to be PG mixed with in-situ soil, as it is the most probable choice to mix with PG. This soil would likely be used whether or not PG was used in the road base mix and is not considered as a risk variable. The soil-PG mixture will be compacted as part of the road construction process leading to high densities in the road base. Other site-specific soil parameters were not defined and are generally less important to the overall risk calculations. Specifically, carbon or clay content and moisture levels are not key factors in the risk determination (i.e., the radiation levels do not vary significantly based on these factors. Gamma ray attenuation for a fixed thickness of shielding is based on the density of the material being penetrated and to a lesser degree the chemical composition. The gamma source strength for a large slab of gamma emitting materials is proportional to the source strength (disintegrations per cc per sec) and inversely proportional to the mass attenuation coefficient[11]. The first term, source strength, can be rewritten as Bq/g x g/cc (pCi/g x g/cc). The second term, mass absorption coefficient is the linear attenuation coefficient divided by density. Both terms are dependent on density (i.e., g/cc or equivalent units). Thus, for practical purposes, the density of the source material is the key factor irrespective of the characteristics of the source material per se.

5. USEPA: What is the basis for limiting phosphogypsum to 50% in the road base? Is there a geotechnical reason, such that structural stability suffers at higher proportions? Is there an optimal range for durability? Alternatively, would administrative controls need to be put in place to maintain this limit during construction? Would an end-user need to address the administrative controls in a specific use request?

Arcadis: Available research on experimental roads reported PG:soil ratios in the range of 1:2 PG:Soil. The EPA in their 1992 BID used a 1:2 mix of PG:sand. This is also the PG ratio in the Polk and Columbia county roads[12] constructed with input on the design and testing of the roads from the University of Miami and the Bureau of Materials & Research, the Florida Department of Transportation.

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[11] Rockwell, Theodore, July 1956. "Reactor Shielding Manual". U.S. Atomic Energy Commission, First Edition.

[12] Chang, Wen F., and Mantell, Murray I., 1990. Engineering Properties and Construction Applications of Phosphogypsum, University of Miami, Phosphate Research Institute, ISBN No. 87024-328-4.

In a study by W.F. Chang et at (Chang, Wen F., Chin, David A., and Ho, Robert, 1989)[13], various ratios of PG to soil were studied. California Bearing Ratio CBR test were conducted on ratios of PG: sand ranging from 100% sand to 100% PG. The PG to sand mixtures showed all mixes had CBR values higher than sand or PG separately. Various radios of PG to soil were used in sections of an experimental road in Polk County Florida. The PG was rototilled into the soil to various depths, A portion was also covered by an asphalt coat. These studies indicate that there is no reason to limit the quantity of PG to be used in a road. The limiting factor would be the measured compressive strength and durability of the admixtures prior to their use in the road. Further studies could establish guidance on the range of PG to soil ratio allowed for various soil types. A 50:50 mixture of PG and local construction materials such as sand or soil is likely to be an overestimate of the actual mix

As noted in the figure below, road design parameters and specifications are better optimized at lower PG:soil ratios. To be conservative of potential risks, the risk assessment considered the upper end of likely reasonable mixture ratios. As stated in previous comments, this parameter provides a linear impact on the risk results. So, if alternate concentrations of PG are desirable, the risks can be easily extrapolated up or down from the existing calculations.

The amount of PG that would be used in a lane/mile of road base depends on many things such as: thickness of the road base, the percent PG in the road base, density of the PG, width of a “lane”. In the end, the appropriate County, State or Federal road authority will have to approve the specifications of the road base used in the design. However, to illustrate the concept, consider a road where 1) lane width is 25 feet, 2) the maximum thickness of the road base mix is 12-inches, 3) the maximum percent PG in the road base is 50%, 4) the dry density/95% proctor can be based off the attached Figure 3.6 from Chang and Mantell 1990[14].

The Figure 3.6 Maximum density curve is based on a PG soil mix, it provides the highest density with PG at 1/6 of the mixture – which can then be extrapolated using the curve for a half/half mixture. Using this range yields a 95% proctor density of 1.9 to 1.98 grams/ cubic centimeter which converts to 118.6 to 123.6 lb/cubic ft.

That said, a 25 ft wide lane for one mile, would require about 3,900 to 4,100 tons of PG per mile, rounded to 4,000 tons/mile.

However, it is the concentration of Ra-226 in the road base that determines the gamma radiation levels. For example, a road with PG at 1/6 of the mixture as described above would have a Ra-226 concentration 3 times lower than the calculations provided in the 2019 risk assessment, and result in doses and risks 3 times lower. As previously indicated, the 2019 risk assessment assumed a 1:1 mix of PG and local soils. This is considered a reasonable upper bound for such a mixture and hence alternative mixtures will have lower concentrations of Ra-226 than were assessed in the 2019 risk assessment and hence, it follows that the doses and risks would also be lower.

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[13] Chang, Wen F., Chin, David A., and Ho, Robert, 1989. Phosphogypsum For Secondary Road Construction, University of Miami, For Florida Institute of Phosphate Research, Publication No. 01-033-077, 01-041-077.
[14] Chang, Wen F., and Mantell, Murray I., 1990. Engineering Properties and Construction Applications of Phosphogypsum, University of Miami, Phosphate Research Institute, ISBN No. 87024-328-4.

36 PHOSPHOGYPSUM

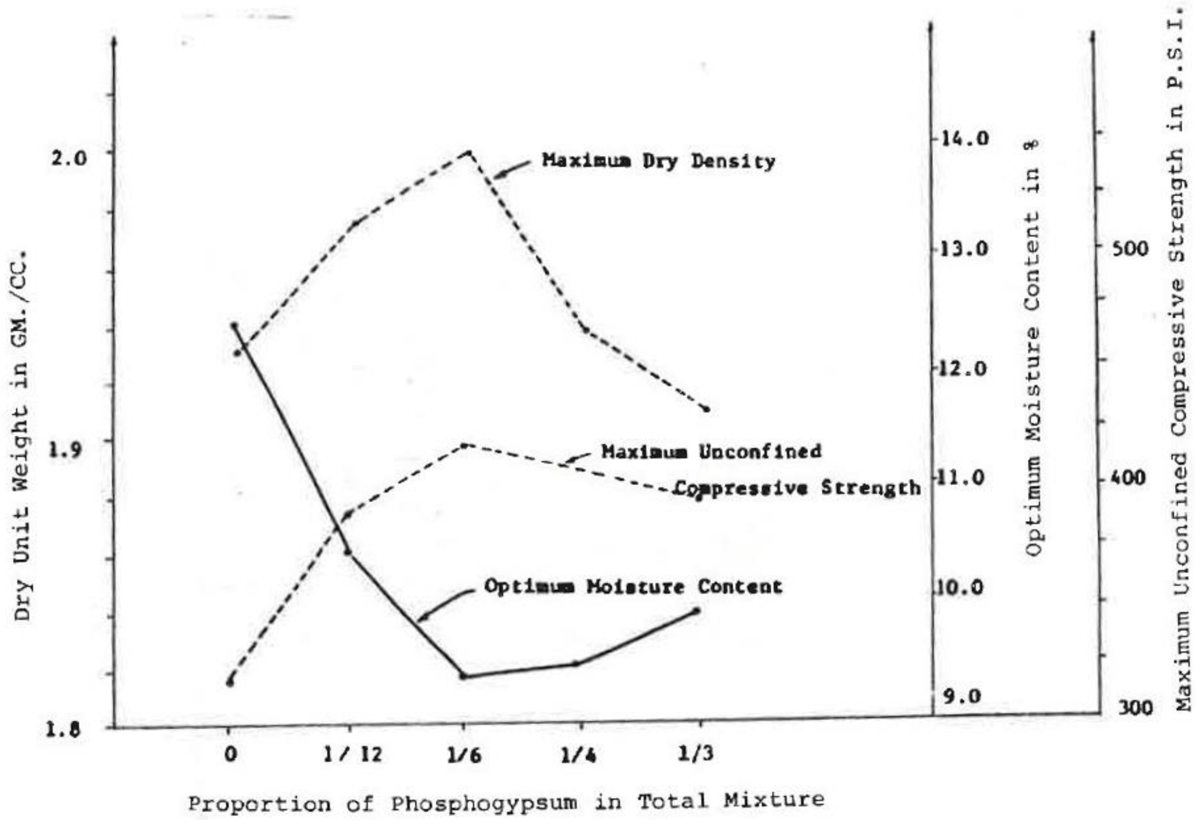

Figure 3.6 Variation in the maximum unconfined compressive strength, optimum moisture and maximum dry unit weight with change in the proportion of phosphogypsum in the various mixtures of clayey sand, sand and phosphogypsum.

6. USEPA: Reviewers had questions related to the conceptual model for the road design, specifically the restriction of the phosphogypsum-containing layer of road base to the area under the pavement. A road model used by the U.S. Federal Highway Administration, "Tech Brief: Bases and Subbases for Concrete Pavements," FHWA-HIF-16-005 (https://www.fhwa.dot.gov/pavement/concrete/pubs/hif16005.pdf) shows a road base which extends 3 to 4 feet (91 to 122 cm) beyond the road cover on each side of the road. In this case, all scenarios would need to account for some gamma exposure from road base material that is not shielded by pavement, and the possibility that phosphogypsum may become airborne at the uncovered edges of the road base.

Arcadis: The risk assessment provided an examination of a conceptual road design with risks estimated for scenarios and exposure pathways expected to be the most dominant. The road design in the risk assessment approximated road design characteristics and plausible exposure scenarios for various types of roads. While some large highways may have exposed shoulders, those roads are unlikely to have pedestrians, cyclists or houses in close proximity. Suburban and urban roads represented a plausible scenario which maximizes exposures for the dominant external gamma pathway. Airborne dust from exposed shoulders is not expected to be a dominant pathway due to the binding properties of PG and the limited potential for substantive intake. Further, road shoulders typically become infilled with vegetation which also suppresses dust.

To explore this question, Arcadis considered the dose and risk impacts for a conceptual road with a 4-foot uncovered shoulder. We estimated results that are not substantially different from that of the original conceptual design of a 15-meter-wide road. Consider the worst case a worker at the center of the road. Gamma rays emitted from the strip (consider the leading or close edge or 7.5 m from the center) would need to travel at an extreme angle (~7.6 degrees) to impact a worker at the center of the road at the dose point (one meter above the surface. From the far edge (8.7 m form the center) the angle is 6.6 degrees. Assuming gamma rays are emitted isotropically, then about 1% of the additional emitted gamma rays (1/90) strike the worker.

Additional gamma calculations were also done with RESRAD for an uncovered road shoulder as described below to confirm the above estimations. Two cases were run with all the parameters fixed with the exception of the area. The original area was 15 m by 100 m, the adjusted area was 17.5 m by 100 m. Table 1 presents the exposure for a worker at the road center in both cases. As indicated the maximum contribution to the dose is external gamma. The increase in dose for external gamma is about 1.5%

Table 1 Dose to a maximumly-exposed worker at the center of a road with constructed with PG

	Direct exposure mrem/year	Inhalation dose mrem/year	Inhalation Dose mrem/year	Total Dose mrem/year
Original Road (15 m x 100 m)	26.11	0.1423	1.918	28.170
Adjusted Road (17.5 m x 100 m)	26.51	0.1465	2.004	28.661
Increase %	1.5%	2.9%	4.4%	1.7%

A similar calculation can be performed with the exposure point at the edge with similar results. The conclusion is that the 3- to 4-foot (i.e., 1 m to 1.2 m) strip along the road has minimal increase in the dose and final risk.

7. USEPA: Are assumptions related to durability and weathering of roads based on documented experience? What are the assumptions regarding the frequency of repaving or other road maintenance/replacement? Are they correlated to the type of road and traffic projections? Would an end-user need to account for such assumptions in a specific use request?

Arcadis: Road maintenance related to weathering roads was not explicitly assessed in the 2019 risk assessment, nor was road maintenance assessed in the EPA 1992 BID. This scenario is not deemed to be an RME condition and would be bounded by risks calculated for the Road Construction Worker. Consequently, road type and traffic projections are not relevant to the risk assessment and would not need to be accounted for in a specific use request.

Potential doses arising from road maintenance are expected to be on the order of those from the Utility Worker scenario. Full repaving activities would be limited to exposures less than those arising from road construction.

Road maintenance is typically done by milling the surface, cleaning, applying tackifier (to assist in binding new asphalt to the underlying asphalt) and new asphalt, leading to minimal disruption of the road base (the PG containing layer). Section 10.5.3 of IAEA 78 Safety Report Series[15] provides several observations on use of PG for road base and suggests PG roads would require less frequent maintenance as compared to roads constructed with other clay-based and limestone materials.

> *Phosphogypsum has successfully been used as a binder for base course mixtures. Phosphogypsum based mixtures are more workable than clay based mixtures. Delays due to rain during construction are reduced because the compacted mixture does not absorb significant amounts of water. Shrinkage cracks and swelling, which often negatively affect the performance of clay based road beds, are greatly reduced. The stability of compacted phosphogypsum mixtures is superior to that of clay mixtures [186] and there is evidence that the use of phosphogypsum, if correctly optimized, leads to a progressive strengthening of the road bed over time [214, 215].*

Further as regards maintenance to date experience indicates minimal maintenance.

> *In Florida, USA, two experimental roads were built in 1986–1987 using both dihydrate and hemihydrate forms of phosphogypsum [224, 225]. The results of the evaluations are reported in Refs [226–228]. It was concluded that phosphogypsum, when subjected to optimum mixing and compaction, could be transformed into a solid of high strength that is effective as a binder to stabilize on-site soil. Phosphogypsum and sand mixtures, stabilized with a small amount of cement, possessed a load bearing capacity higher than that of locally mined limestone, which was at that time the material of choice for road bases in the region. It was also demonstrated that the incorporation of phosphogypsum into a cement based mixture for making 'roller compacted concrete' (a form of concrete widely used for road construction) led to improved compaction and strength properties [229]. The road bed described in Ref. [224] is shown in Fig. 49, which shows the condition after 25 years of use. The picture was taken during routine resurfacing. While the phosphogypsum is clearly not mixed in fully with other road bed materials, it has, nevertheless, lost none of its load bearing strength. As a result, the only maintenance requirement was a new layer of asphalt.*

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[15] International Atomic Energy Agency (IAEA) 2013. *Radiation protection and management of norm residues in the phosphate.* Vienna. (Safety reports series, ISSN 1020–6450; No. 78) STI/PUB/1582.

FIG. 49. Experimental road bed in Florida, USA, incorporating phosphogypsum (courtesy: Florida Industrial and Phosphate Research Institute).

In summary, the dose and risk from repairs conceptually cannot be greater than the dose and risk from the original road building since the PG is covered by concrete, asphalt or other material. The Risk Assessment provides the RME scenarios representing categories of exposure conditions with other minor exposure scenario representing lower risks. The example of road maintenance is not considered an RME and requires no further assessment.

Environmental and exposure pathways:

8. USEPA: The risk assessment would benefit from additional analysis of water pathways. Appendix 3 states that “Leaching to groundwater (or surface water) is likely not a complete exposure pathway for the petitioned PG reuse in road construction. This is because roadways are sloped to drain precipitation and paving will act as a barrier to infiltration through the compacted road base beneath. Despite this, literature regarding leaching and water quality was evaluated as part of this screening assessment (see the section titled “Leaching and Water Quality”).” (p. 4) At least qualitative consideration should be given to direct contact with surface or groundwater due to flooding events, high water tables, and the presence of karst in phosphate lands. Likewise, reviewers suggested that the risk assessment consider the weathering of the road – will it develop fractures, potentially leading to infiltration resulting from road weathering cause leaching?

Arcadis: Previous risk assessments including 1992 Background Information Document for "Potential Uses of Phosphogypsum and Associated Risks", EPA 1992[16] and SENES 1997[17] examined the potential for impacts to groundwater and surface water pathways. These studies found no realistic potential for impacts to these pathways. Groundwater and surface water pathways were identified to be inconsequential by the EPA BID calculations. Radionuclides were not calculated to reach the nearby well water via the groundwater for almost 10,000 years. For off-site (more distant) wells and river water, radionuclides were not calculated to reach these waterbodies via groundwater for almost 100,000 years. The EPA BID reported in Note C, Table 4.15, that groundwater velocities and retardation factors in the modelling were the factors contributing to this result.

> *No radionuclides are calculated to reach the on-site well via the groundwater pathway for almost 10,000 years, or the off-site river or well for more than 100,000 years because of groundwater velocities and retardation factors.*

Exploratory calculations were completed by SENES Consultants Limited (1997) (now Arcadis Canada Inc.) to review how EPA calculations for the Background Information Document (BID) and Final Rule. SENES reconstructed the BID calculations with nearly identical results as shown in Table A.1 from SENES 1997. With respect to water pathways, the results were consistent, showing that there was no impacts or very limited results, orders of magnitude below other pathways of interest, as shown in the table.

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[16] United States Environmental Protection Agency (USEPA) 1992. Potential Uses of Phosphogypsum and Associated Risks, Background Information Document. U.S. Environmental Protection Agency, Air and Radiation (ANR-459). EPA 402-R92-002. May.

[17] SENES Consultants Limited, 1997. Application for Exemption – For Use of PG in the Construction of Thornhill Road, Polk County Florida. Prepared for the Florida Institute of Phosphate Research (FIPR). Draft.

Table A.1

BID RECONSTRUCTION RESULTS
(Asphalt Road Constructed Using Phosphogypsum Containing Radium-226 At 26 pCi/g)

	Comparison of BID results and reconstructed results Dose, mrem per year (Lifetime risk per year of exposure)	
	BID Dose(Risk)	BID Reconstruction Dose(Risk)
Construction Worker - gamma no shielding from equipment - gamma with shielding from equipment - inhalation of dust - dry site - inhalation of dust - humid site	 41 (1.5×10^{-5}) 25 (9.0×10^{-6}) 2.5 (2.2×10^{-7}) 1.0 (8.4×10^{-8})	 42 (1.3×10^{-5}) 25 (7.6×10^{-6}) 2.5 (2.1×10^{-7}) 1.0 (8.6×10^{-8})
Person driving on road - gamma	 0.22 (8.2×10^{-8})	 0.23 (7.2×10^{-8})
Critical Population Group - gamma, 100 m off-site - ingestion of well water - ingestion of food	 0.043 (1.6×10^{-8}) —[c] —[c]	 <1.0×10^{-7} (<1.0×10^{-13})[a] 0.0037 (8.2×10^{-10})[b] —[b]
Off-site Individual - river water from groundwater - river water from surface runoff	 —[c] 0.02 (1.5×10^{-9})	 —[c] 0.02 (2.2×10^{-9})

Notes:

a. Critical Population Group gamma dose estimates are less than the stated values. These values were calculated in MicroShield without taking account of shielding provided by the upper layer of road material. Risks for this pathway are calculated based on a risk factor of approximately 3.9×10^{-7} $mrem^{-1}$ (EPA 1989). As MicroShield does not provide radionuclide-specific doses, this alternative approach to the risk calculation was utilized. For further information see Part II, Section 3.3.

b. The values stated for well water ingestion by the CPG correspond to year 10,000. No radionuclides were calculated to reach the well water in any of the prior years that were calculated. The food pathway for the CPG was not modelled as it is expected to have a similar result, or less, than the well water pathway. This is based on the BID assumption that food eaten by the CPG is irrigated with well water.

c. For these pathways, no radionuclides were calculated to reach the on-site well via the groundwater pathway for almost 10,000 years, or the off-site river or well for more than 100,000 years because of groundwater velocities and retardation factors.

9. USEPA: Related to the question of whether interactions with ground and surface water are possible, if dissolution or leaching does take place, is there a potential for uptake and bioaccumulation by organisms of any of the radiological constituents of phosphogypsum?

Arcadis: As noted above, radiological groundwater and surface water impacts were not expected to be relevant in the overall risk determinations for this potential use of PG. By extension subsequent pathways to groundwater and surface water were shown not to be relevant, as documented in BID 1992, Table 4-15 and SENES 1997, summarized in Table A.1 above.

Exposure scenarios/receptors:

10. USEPA: The risk assessment should address the handling of the phosphogypsum between the stack and road construction. The risk assessment should incorporate all handling and processing steps necessary to implement the use. Presumably, pure phosphogypsum would be trucked to a batch plant or other mixing facility, prior to transportation to the construction area. These scenarios should be explicitly considered, including the potential for dust and surface runoff.

Arcadis: Known construction procedures involve PG mixing at the road construction site by placing the PG in the desired location and mixing it into existing or additional soil. Existing calculations consider dust generation at the construction site. These dust intake pathways were found to be orders of magnitude less than external gamma exposure for the construction worker. PG is not batched or mixed prior to use. With respect to loading PG in a truck, the frontend loaders and/or scrapers used to remove PG from a stack to a holding area stockpile at the plant facility for subsequent loading are closed air-conditioned cabs.

Any potential dust exposure to the truck driver or equipment operator is expected to be substantially less in concentration and duration of exposure, compared to the construction worker

For example, as can be seen in the RESRAD output in Appendix C of the Draft Risk Assessment, the annual dose for a road construction worker at the center of the road working on exposed road base, who would experience more direct exposure than a truck driver, inhalation exposure represents 0.5% of the total annual dose. This is presented in the table below.

Road Construction Worker Uranium-238 Dose Exposed to Road Base at Center of Road			
Total Annual Dose (mrem/year)	External Gamma (mrem/year)	Inhalation (mrem/year)	Incidental Ingestion (mrem/year)
28.17	26.11	0.1423	1.918
100.0%	92.7%	0.5%	6.8%

Consequently, the contribution of dust intake for the truck driver or equipment operator is not expected to be relevant to the overall dose and risk calculation.

In addition, consider potential gamma exposures as illustrated by an equipment operator loading the truck using a medium frontend loader. The rate of loading for a 2.25 cubic yards (cy) capacity bucket is 100 cy/hour (Means 2000). Assuming the operator fills ten 20 cy trucks results in an exposure time of two hours per day. In addition, the operator of the front-end loader would be inside a cab located above the PG stack and shielded by the cab. The cab shielding (1 cm of steel) reduces the gamma dose by 50%. This results in the cab operator receiving an annual dose of about 10 % of the construction worker dose (25% exposure duration-2 hours/day and less than 50 % of the gamma dose). The risk is also reduced by at minimum a factor of ten.

11. USEPA: The truck driver scenario only includes direct external exposure from gamma radiation. It should explicitly consider inhalation or ingestion during loading, unloading and truck cleaning.

Arcadis: See comments above. While these additional exposures can be developed, given the discussion in the previous comment, we see no realistic potential for a substantive increase in the calculated risk due to inhalation and ingestion of dust. As described in the response to comment 10, the annual dose for a road construction worker at the center of the road working on exposed road base, who would experience more direct exposure than a truck driver, inhalation exposure represents 0.5% of the total annual dose and ingestion represents 6.8% of the total dose. As a truck driver in the cab of a truck would have less exposure via these routes of exposure than a road construction worker, the relatively small incremental increase in dose has little impact on the resulting risk estimate. Assuming similar percentages for inhalation (0.5%) and incidental ingestion (6.8%) for the truck driver scenario with an annual dose of 18.6 mrem/year, inhalation would be 0.09 mrem/year and ingestion would be 1.27 mrem/year for a total of 20 mrem/year. However, ultimately once converted to risk over a 5-year exposure duration the resulting cancer risk (presented to one significant figure) remains the same (i.e., 20 mrem/year divided by 1,000 mrem/rem, multiplied by the cancer risk coefficient of $5.0x10^{-4}$ per rem = $5x10^{-5}$).

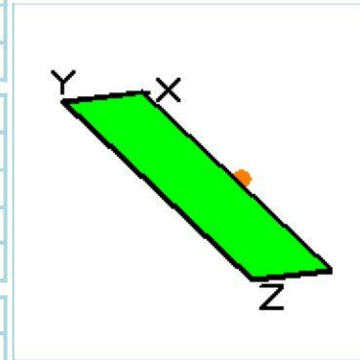
12. USEPA: The utility worker scenario should consider a worker in a trench that parallels the road, rather than crossing it.

Arcadis: For the Utility Worker Arcadis selected a trench that crosses the road to simply represent an RME scenario, providing a near upper-limit exposure. This scenario provides exposure to an excavated surface on both sides of the worker. The exposure rate as reported in the Risk Assessment is 4.2 μR/hr.

Considering a trench that parallels the road on either side provides only one exposed surface. The result is an exposure rate approximately half (2.15 μR/hr) of the exposure rate arising from the trench considered in the 2019 Risk Assessment. Below are excerpts of a MicroShield output for a trench along the length of the road.

MicroShield Output for Trench Along Length of Road

Source Dimensions	
Length	1.5e+3 cm (49 ft 2.6 in)
Width	1.0e+4 cm (328 ft 1.0 in)
Height	25.0 cm (9.8 in)



Dose Points			
A	X	Y	Z
#1	1.6e+3 cm (51 ft 10.8 in)	25.0 cm (9.8 in)	5.0e+3 cm (164 ft 0.5 in)
#2	1.6e+3 cm (52 ft 10.8 in)	25.0 cm (9.8 in)	5.0e+3 cm (164 ft 0.5 in)
#3	1.6e+3 cm (53 ft 10.8 in)	25.0 cm (9.8 in)	5.0e+3 cm (164 ft 0.5 in)

Shields			
Shield N	**Dimension**	**Material**	**Density**
Source	1.32e+04 ft^3	Concrete	2.25
Air Gap		Air	0.00122

Results - Dose Point # 1 - (51.9,8.20e-01,1.64e+02) ft					
Energy (MeV)	**Activity (Photons/sec)**	**Fluence Rate $MeV/cm^2/sec$**	**Fluence Rate $MeV/cm^2/sec$**	**Exposure Rate mR/hr**	**Exposure Rate mR/hr**
		No Buildup	**With Buildup**	**No Buildup**	**With Buildup**
Totals	**1.111e+09**	**5.692e-01**	**1.237e+00**	**9.726e-04**	**2.149e-03**

In the extremely unlikely scenario of a 100 m trench down the center of the road, the resulting exposure rate is estimated by assuming two exposed surfaces results in an exposure rate of 4.3 μR/hr. The incremental length of the trench provides no substantive increase in dose rate due to the extreme angle and distance of the additional exposed surface.

13. USEPA: There may be road user scenarios worth considering, particularly if phosphogypsum may extend beyond the paved areas, e.g., pickup/delivery drivers, workers who mow the shoulders. How would these compare to the currently-modeled scenarios?

Arcadis: As discussed in a previous question, the risk assessment provided an examination of a conceptual road design with risks estimated for scenarios and exposure pathways expected to be the most dominant. The examined exposure scenarios were included in the risk assessment in order to provide the likely maximum scenarios and the scenarios were agreed to by EPA.

The conceptual road design in the risk assessment approximated road design characteristics common in rural, suburban and urban settings and provided plausible exposure scenarios for various types of roads. While larger highway designs could be built, these require larger right-of-way widths of approximately 150 to 300 feet.[18] This leads to larger set-backs for near-by residential housing, resulting in lower dose and risk. Interstate highways typically have restricted access to cyclists and pedestrians, eliminating these

[18] The Federal Highway Administation, Highway History, The Size of the Job, available at https://www.fhwa.dot.gov/infrastructure/50size.cfm

exposure scenarios for large highways. Suburban and urban roads represented a plausible scenario which maximizes exposures for the dominant external gamma pathway.

With respect to pickup/delivery drivers and workers who mow the shoulders the dose assessments for road users provided in the 2019 risk assessment would be bounding and estimate higher doses than doses for other types of road users.

For example, a truck driver may drive 50% of the workday but would likely be on PG road only 25% of the driving hours due to the use of the extensive network of existing roads. Drivers in delivery trucks would also gain the benefit of shielding from the vehicle structure, which is typically a factor of approximately 0.6 (BID 1992). Overall, a scenario with a delivery driver is estimated to result in a dose that is approximately 30% of that estimated for the road user in the 2019 risk assessment.

A worker mowing the grass beside the road may be working for close to a full day but again would likely be beside a PG road only 25% of the driving hours due to the work on the extensive network of existing roads. This worker would also gain the benefit of shielding from the vehicle structure, which is typically a factor of approximately 0.6 (BID 1992). Considering the worker is located beside the road, the exposure to PG is reduced by approximately 50%, as shown in the 1992 risk assessment. Overall, a scenario with a worker mowing grass beside the road is estimated to result in a dose that is approximately 30% of that estimated for the road user in the 2019 risk assessment.

Parameters:

14. USEPA: The worker exposure duration of 5 years is based on both 25% of a 20-year career and of 70% of the project completion time for a major road project (p. 2-9). If the use of phosphogypsum as road base becomes regular practice, would workers not be expected to work on subsequent projects that could also involve phosphogypsum?

Arcadis: The road construction project examples provided in the discussion of this parameter were some of the largest (longest) projects identified. The parameter estimation uses worker statistics and the likelihood of other road construction methods to continue, to estimate a reasonable exposure duration over a construction worker's career.

The Bureau of Labor Statistics employee tenure in 2018 shows that the median years of tenure with current employer for construction industry between 2008-2018 ranges from 3.5 years in January 2008 to 4.3 years in January 2012 (See Table 5 below).

Table 5. Median years of tenure with current employer for employed wage and salary workers by industry, selected years, 2008-2018

Industry	January 2008	January 2010	January 2012	January 2014	January 2016	January 2018
Total, 16 years and over	4.1	4.4	4.6	4.6	4.2	4.2
Private sector	3.6	4.0	4.2	4.1	3.7	3.8
Agriculture and related industries	4.3	4.8	4.1	3.6	4.5	4.6
Nonagricultural industries	3.6	4.0	4.2	4.1	3.7	3.8
Mining, quarrying, and oil and gas extraction	4.1	4.8	3.5	4.0	4.6	5.1
Construction	3.5	4.2	4.3	3.9	4.0	4.1

Burmaster (2000)[19] analyzed employee tenure data from The Bureau of Labor data. The report provides statistical analysis of those data for a wide variety of occupations. For construction in general, the data for men (women not available) show a mean and 95th percentile of 3.23 yr and 12.48 yr. For construction laborer's specifically, the data for men/women show a mean and 95th percentile of 1.74 yr / 1.81 yr and 5.93 yr / 7.08 yr, respectively.

Burmaster (2000) also provides the distributions (in terms of empirical percentiles) for projected duration in years for each occupation type. The table below shows the worker tenure percentile projections for these selected industrial subsectors.

Distribution of Male Worker Tenure by Industry Type

Industry Sector		Percentiles											
	Mean	10	20	30	40	50	60	70	80	90	95	97.5	99
Construction	3.23	0.21	0.45	0.74	1.10	1.54	2.13	2.98	4.39	7.70	12.48	18.24	26.23
Construction Labor	1.74	0.10	0.22	0.36	0.53	0.74	1.01	1.40	2.03	3.45	5.93	11.53	21.26

To be consistent with methodologies to determine RME exposures and risk Arcadis considered that not all construction work will be on PG roads due to possible alternate construction methods and maintenance work for the vast network of existing roads.

The value used in the Risk Assessment represents a portion of industry tenure spent constructing roads: 80% of 25-year worker tenure recommended by USEPA (2014) constructing roads = 20 years; 25% of road construction time spent using PG = 5 years. Based on the employment statistics provide above the actual exposure is likely to be much less than 5 years.

15. USEPA: The TFI Risk Assessment for the Truck Driver scenario uses a density of 1.12 gm/cm3 for phosphogypsum in the truck. U.S. Department of Transportation, Federal Highway Administration, Research and Development Turner-Fairbank Highway Research Center, User Guidelines for Waste and By-Product Material in Pavement Construction, FHWA-RD-97-148 gives a specific gravity range from 2.3 – 2.6 gm/cm3 (p. 19-6), and in a second location states, "specific gravity of solids ranges from 2.30 to 2.50, with an average in the 2.35 to 2.40 range." (p. 19-14). TFI assumes that loose PG in the truck will be about half the density of that identified in the FHWA document. PG that is excavated and loosely placed in a truck will certainly have a higher porosity, but what is the basis for assuming this specific value?

Arcadis: The specific gravity values of 2.3 to 2.6 (unitless) are common in literature about PG. For example, Chang and Mantell 1990[20], reported the average specific gravity values of seven Florida

[19] Burmaster, David E., 2000, *Distributions of Total Job Tenure for Men and Women in Selected Industries and Occupations in the United States, February 1996*. Risk Analysis, Vol. 20, No. 2, 2000.
[20] Chang, Wen F., and Mantell, Murray I., 1990. Engineering Properties and Construction Applications of Phosphogypsum, University of Miami, Phosphate Research Institute, ISBN No. 87024-328-4.

sources of PG varied between 2.33 and 2.43. The specific gravity values of this magnitude however related to particle specific gravity and ignores the porosity / void space in the bulk material. The same reference reports the maximum dry bulk density of PG following compaction to range between 90.3 to 102.7 lb/ft^3. This compacted bulk density converts to 1.4 to 1.6 g/cm^3. For material excavated and loaded into a truck a swell factor of 20% - 30% is not uncommon for materials such as soil, sand or gravel. For the Risk Assessment the density of the PG in the truck can be supported using a bulk density of 1.4 g/cm^3 with a swell factor of 25% (1.4/1.25) resulting in PG density during transport of approximately 1.12 g/cm^3.

As previously indicated, density is an important factor in assessing potential doses arising from road building. The in-place post compaction density of PG in road base will be specified along with other physical characteristics by the appropriate local, state or federal highway authority. The densities used in the current (2019) risk assessment are considered appropriate for the purpose of risk assessment.

16. USEPA: Assumed inhalation rates may need further justification. As stated in the TFI Appendix 2 (p. 2-11): “The RESRAD default inhalation rate of 8,400 cubic meters per year (m3/yr) was used for the nearby resident receptor. A higher inhalation rate of 11,400 m3/yr was assumed for road construction workers and utility workers. This value was the RESRAD version 6 default for industrial workers and assumes an hourly rate of 1.3 m3/hr.” When 11,400 m3/yr is multiplied by the fraction of time spent outdoors (on site) the result is the Road Construction Worker annual inhalation rate of 2,622 m3/yr. This value is about 9% larger than the worker inhalation rate used by the International Commission on Radiation Protection (Guide for the Practical Application of the ICRP Human Respiratory Tract Model, 2002). However, compared to the EPA Exposures Factors Handbook (EPA 2011) Tables 6-1 and 6-28, the inhalation rates for moderate and heavy activities, the RESRAD rate of 1.3 m3/hr is lower than the low end of the range provided for EFH worker inhalation rate. The low end of the range is 1.6 m3/hr and the high end is 4.8 m3/hr, several times higher than the RESRAD rate.

Arcadis: RESRAD exposure parameters for workers were applied where available. Considering the exposure duration of a full day, it is expected that a moderate inhalation rate would be more realistic of the overall inhalation rate as heavy activities would not be continuous throughout the day. The values in Table 6-28 of EPA Exposure Factors Handbook (EPA 2011) ranging from 1.6 m^3/hr for the low end of the moderate activity level, which is for adult females, to 4.8 m^3/hour for the high end of the heavy activity level, which is for adult males, is based on information included in a dated guidance document (i.e., EPA 1985).

More recent studies are referenced in the Exposure Factors Handbook (EPA 2011), several of which were specifically conducted on workers or more specifically construction workers. One study of “high risk” populations exposed to ozone in the Los Angeles area found a mean inhalation rate of 0.78 m^3/hour for healthy adults and a mean of 1.5 m^3/hour for construction workers during a 10-hour work shift (Linn et al. 1992). Linn et al. (1993) studied inhalation rates of construction workers (i.e., laborers, iron workers, and carpenters) during work and break times based on a relationship to heart rate and determined a mean inhalation rate of 1.68 m^3/hour with a standard deviation of ± 0.72. However, estimates of extremes (e.g., 99th percentile) were outside the calibration range of the model and would not be appropriate for an RME. Lastly Allan et al. (2009) determined mean inhalation rates of 1.4 m^3/hour for male construction workers and 1.25 m^3/hour for female construction workers based on probability density distributions generated using Monte Carlo simulation. Therefore, the inhalation rates used which are based on RESRAD defaults are appropriate mean estimates.

While upper percentile estimates may represent a relative extreme, those assumptions are not appropriate for a reasonable maximum exposure scenario. Regardless, using an inhalation rate up to 3 times higher resulting in inhalation doses 3 times higher would still add relatively little to the overall dose and risk as the inhalation route of exposure results in a dose that is orders of magnitude less than external radiation and an order of magnitude or more less than ingestion exposure.

17. USEPA: It is difficult to evaluate the appropriateness of the worker exposure parameters TFI used in Appendix 2, in part due to a lack of detail in discussion of road base and pavement construction process, procedures, and equipment. Page 3-2 states “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.” Would different workers have different roles, such as walking directly behind machinery versus walking on the road shoulder? What would happen to the doses if this ratio was changed, such as 75% middle of the road/ 25% edge?

Arcadis: The assumption of the construction worker exposure at both the center of the road and the edge of the road approximates the expected movement of a worker throughout a full workday. Shifting this parameter to the extreme of working 100% of the time in the center of the road would provide a minor increase in the exposure and risk.

As shown in the calculations in a previous question above, assuming the worker spends 100% of the time in the center of the road provides an annual exposure of 28 mrem/yr. This is a 27% increase from the 22 mrem/yr exposure reported in the risk assessment, based on 50% in the middle of the road and 50% along the edge of the road, but makes no change to conclusion that the risk is significantly below 3:10,000. But it is unrealistic to assume a work stands in one spot all day. If a worker did so, he or she would have a very low inhalation rate.