REVIEW OF THE JBS&G 2023 REPORT: MANDENA COMMUNITY RADIATION STUDY

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Overall Comments

The data provided in the report are a welcome step in filling data gaps identified in Swanson (2019). The study contributes important information required to evaluate radiation doses to community members in the area surrounding the QMM ilmenite mine. The data are of broader interest because studies of radionuclide levels near ilmenite mines and mines producing rare earth minerals are very rare. In particular, the study provides valuable new information on radionuclide levels in food in an area where communities rely on subsistence farming and fishing. Lessons learned while conducting the study can inform future work.

Radiation Doses

The evidence in the report indicates that estimated radiation doses are dominated by natural background sources. The estimated doses presented in the report are within ranges reported for other high natural background areas around the world.

All of the estimated doses are well below 100 mSv, which is the level established by the International Commission on Radiological Protection (ICRP) above which effects from exposure to radiation start to be observable. Doses below 100 mSv still have a risk of effects associated with them, but the risks become smaller and smaller the lower the dose gets, and effects attributable to such low doses are very difficult to find or prove.

All of the estimated doses are below the lowest level deemed by the ICRP to be when interventions are justifiable. This level is 20 mSv/y. In other words, the ICRP has determined that the risks associated with doses below 20 mSv/y are so low that the benefits of intervention to reduce radiation levels to even lower levels would be very difficult or impossible to measure.

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The results indicate that doses from the combination of dust inhalation, drinking water, and eating fruits, vegetables, grains, fish and shellfish are not a concern. *The key remaining question is "what is the chance that doses could be higher than those calculated in the report?".* This question is not only about the protection of the general population, but also more sensitive or more highly-exposed individuals, such as the 15 year-old critical group where the estimated doses were up to 12 mSv/y.

In its discussion of total dose, JBS&G states external gamma radiation may, in places, "be the most significant contributor to overall dose". Gamma radiation levels are highly variable (over several orders of magnitude) so effects on total dose can also vary widely. According to information in Figure 16 of the report, exposure to the higher range of gamma radiation levels in the study area could result in total doses being above the ICRP intervention level of 20 mSv/y – possibly substantially above - depending upon the individual or group. Despite this observation, there is minimal discussion of this figure. There is no discussion of where the individual communities used for the dose calculations might fit within the wide range of gamma radiation levels. The report does not provide any analysis or discussion of sub-groups of people who may receive doses above 20 mSv/y.

Confidence in the Estimated Doses

Unfortunately, the confidence that doses have not been underestimated cannot be expressed quantitatively because of limitations in the study design. Guidance regarding Data Quality Objectives was not consistently nor completely followed. There may be a very low probability that doses were underestimated– but we don't have the data quality to demonstrate that. An example of a quantitative statement is "we are 95% confident that 80% of the doses will be less than the ICRP intervention level of 20 Sv/y. Instead, the level of confidence can only be expressed as a narrative, with reliance on professional judgement.

If a qualitative narrative is the only way of explaining confidence in results, an accessible, clear explanation of the level of conservatism (i.e, 'erring on the safe side') should be provided. This is lacking in the report. Mention of specific conservative approaches and assumptions is scattered throughout the report, but a clear explanation located in one place is not provided. Conservative assumptions can include choosing to use longer exposure periods or higher than the average radionuclide concentrations in dust, water or food. Using these more conservative assumptions helps address the chance that we may have missed particular situations where exposures are higher. A conservative approach includes examining where and when and why doses could be higher

Few studies can achieve very narrow margins of error. Because of that, it is important to offer transparent explanations of "how sure you are" in the conclusions. It is particularly important to explain the consequences of coming to an incorrect conclusion.

Incremental Contribution of the QMM Mine to Radiation Doses

The contribution of the QMM mine to total dose was estimated to be a maximum of 0.6 mSv/y, which is less than the regulatory limit for incremental dose above background of 1 mSv/y. The evidence presented in the report in support of this estimate is difficult to find and interpret. In particular, the evidence for the contribution via water discharges is weak. The water data in the report are from periods when there were no wastewater discharges from the mine. The design of sediment sampling was insufficient to produce reliable estimates of incremental mine-related radionuclide concentrations. The data used for estimation of dilution in the Mandromondromotra River were not presented in the report.

The primary argument used in the report regarding the incremental contribution of the mine to radiation dose is that the contribution is so small relative to the high variability of the natural background radiation that it is very difficult to discern. The data in the report do not provide convincing support for this argument. Only gamma radiation levels show "large variability". Measurements of radionuclide concentrations in dust, water and food are not nearly as variable as gamma radiation. The variability is commensurate with the combination of measurement error associated with levels close to detection limits, and sampling error associated with how well (or not) the sample design accounts for important confounding variables such as water flow, sediment and soil texture, size, fish size and age, and local vs long-range wet and dry deposition.

A Comment on Risk Communication

There are many potential causes of the persistent concern and anger associated with radiation in the Mandena region. The report ascribes the concern and anger to "misunderstanding and local myths" and expresses hope that "provision of these facts will assist in reducing local concerns". Fear and concern are not only caused by lack of information or understanding. They are more often associated with a sense of outrage. The violation of social or cultural interests and values most often underlies outrage. Because of this, science, no matter how sound and credible, is never enough. The fundamental principles associated with preventing or managing outrage include transparency, accessible science, tangible benefits, open and inclusive dialogue, clarity regarding who is accountable, and consistent application of corporate and government policy.

Way Forward

The report recommends a focus on water-based pathways leading from the QMM mine in future work. I agree. I support the recommendation that ongoing radiation monitoring is targeted to pathways requiring regular confirmation that radionuclide levels remain low, as well as pathways which might be subject to future increases in radiation levels.

I recommend that there be an assessment of the potential for higher doses to particular groups – starting with the 15 year-olds critical group where the estimated doses were up to 12 mSv/y. Scenarios where exposure may be higher in specific pathways should be developed and evaluated for likelihood. These scenarios should include exposure to gamma radiation. Total dose estimates for woodcutter exposure to gamma radiation, dust inhalation, and water and food ingestion would have addressed questions about whether sub-groups such as woodcutters receive total doses which differ from total doses for the general population.

I note the statement "ongoing management of radiation at the Mandena mine must remain a focus of Rio Tinto, QMM and Government Regulators". I also note that the ALARA principle is invoked, consistent with the use of ALARA when there are important uncertainties still to be addressed.

I also support the recommendation that future monitoring should involve regulators and local communities. Stakeholder involvement at all stages from design through communication of results has been shown to be effective in building trust and increasing mutual understanding.

Sum-Up

The study makes important contributions to knowledge of radionuclide levels and radiation doses in the Mandena region. Data which have long been scarce in the literature (notably levels of radionuclides from both the uranium and thorium decay chains) are a welcome addition, particularly given the likely increase in mining in regions containing rare earth minerals. It is particularly notable that the data were collected during the COVD-19 pandemic, with all of its associated challenges.

The study approach had several strengths and some important weaknesses. The primary weakness was that the Data Quality Objectives Process was not followed consistently or completely. This created substantial difficulties in evaluating the level of confidence in the data and in the subsequent calculations of radiation dose.

The estimated radiation doses were low and within global ranges of mineral sands areas. The estimated doses from dust inhalation, drinking water and eating plant-based foods, fish and shellfish did not exceed the ICRP intervention level of 20 mSv/y. However, these dose estimates did not include exposure to gamma radiation. Such exposures may result in doses greater than 20 mSv/y, although this may only occur rarely and for specific sub-groups of people with specific lifestyles.

There is still important work to be done to more confidently establish the mine-related incremental contribution to total dose.

The main issue with the report is the leap made from the data to overarching conclusions without clear or sufficient statements about the level of confidence in those conclusions. In particular, conclusions presented in the Executive Summary (which is often the only part of the report which will be read) are definitive, with no acknowledgement of remaining uncertainty. Transparent and thorough discussion of the level of confidence in conclusions and the consequences of being wrong adds to credibility rather than detracts from it.

A Comment on Figures

The figures describing overall results in the main body of the report are not very effective or accessible. The labels on maps within each figure are fuzzy and difficult to decipher. It is not clear when the large-font sample numbers on the figures correspond with the number of baseline samples and when they correspond with the number of samples in the study. Sometimes it looks like the sample numbers might be baseline samples plus study samples. I couldn’t reconcile the sample numbers with the information in the Appendices. The labels on the axes of graphs were very difficult to read and the data points were tiny. The water graphic was particularly difficult to decipher. The cryptic nature of these figures made it necessary to refer to the Appendices for a detailed review.

Organization of This Review

This review is presented in the order used in the JBS&G report, starting with the Executive Summary and then proceeding through the Methodology, Results for the 6 primary exposure pathways, Total Effective Dose, Mine Contribution, Discussion and Conclusion.

Detailed comments and analysis are provided as Attachments corresponding with specific Appendices to the JBS&G report.

The locations given for quotations, tables, figures etc are the original table numbers for the main body of the report and pdf pages for the Appendices.

Executive Summary

Context

I acknowledge the substantial efforts of JBS&G to conduct and complete the study over a period which included the COVID-19 pandemic. The efforts made to train local staff, deal with sampling, shipping and analytical logistics, choose and then implement a method for gathering information on the types and quantities of food consumed in the region and acquire sufficient sample volume to achieve low detection limits are noteworthy.

The context provided by JBS&G for understanding the doses presented in the report is useful from a regulatory and scientific point of view. However, the statement “it is important to provide context to the reader to allay any potential misinterpretations leading to unnecessary fear or concern” is an unfortunate example of the condescending tone which is still quite common when communicating risk from radiation exposure. Fear and concern are not only caused by lack of information or understanding. They are more often associated with a sense of outrage. Outrage is difficult to manage, therefore, causes of outrage must be understood and addressed early, continuously, and consistently.

> “Thirty years ago, Slovic (1987) presented evidence that the higher the “dread risk” and the “unknown risk”, the lower the degree of risk acceptance. “Dread risk” includes characteristics such as: *lack of public control*; high consequences; *inequitable distribution of risk*; long-term effects; and, increasing risk with time. “Unknown risk” includes characteristics such as: *risk that is not observable or tangible; risk that is unknown to those exposed; delayed effects*; and, emergent risk.” (Swanson et al. 2017). I have italicized the specific causes which may be most applicable in the case of the QMM mine and surrounding communities.

In my experience, it is the violation of social or cultural interests and values which most often underlies outrage. Because of this, science, no matter how sound and credible, is never enough. And communication of the science must be accessible, respectful, and inclusive. I will return to this theme when discussing the “Way Forward” section of the Executive Summary.

Key Findings

The estimated doses from food, water and dust inhalation in the area surrounding the QMM mine are within the range reported from other areas in the world with high natural background levels of radionuclides. The recommendations of the International Commission of Radiological Protection (ICRP) regarding "existing exposure situations" are relevant and are what are referred to by JBS&G. "Existing exposures" already exist when a decision on control is required, such as those caused by natural background radiation (ICRP 103). ICRP 103 recommends that interventions are unlikely to be justifiable for exposure to natural background radiation between 1 mSv and 20 mSv per year.

Average annual doses to all age categories were less than the ICRP "intervention level" of 20 mSv/year. However, the average annual dose of 12.2 ± 2 mSv for the critical group (15 year-olds living in Andrakaraka) is not that far-removed from 20 mSv given the uncertainties associated with studies such as this. It is conceivable that a combination of exposure to food, water and dust combined with particularly elevated natural background gamma radiation (e.g. regular exposure to black sand areas) might push doses above 20 mSv/year (as shown in Figure 16 on p. 42 of the report where maximum total doses exceed 40-50 mSv/year). These doses might be for small sub-groups of the population only, but they illustrate the importance of two fundamental issues: (1) the level of confidence that radiation doses to specific groups have not been underestimated; and (2) the importance of the ALARA (as low as reasonably achievable) principle.

There needs to be high confidence that doses have not been underestimated to specific groups of people with high sensitivity to radiation and/or higher than average exposures. The level of confidence in the conclusions presented in the report cannot be determined quantitatively because of limitations of the study design. The study design limitations were created by inconsistent or missing components of the Data Quality Objectives process. I present and discuss this issue in detail later in this review as well as in an Attachment.

ICRP 103 states that its recommendations "emphasize the key role of the principle of optimization". The principle of optimization states that the likelihood of incurring exposure, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable (ALARA), taking into account economic and societal factors.

The Executive Summary states that the incremental contribution of the QMM mine to total dose "is estimated to be less, and potentially significantly less, than 0.6 mSv/y, which is below the regulatory limit of 1 mSv/y above the naturally occurring dose." Direct mine water discharge was described as having the highest potential for the greatest movement of mine generated radionuclides into surface water, the food chain, and local community diet. "Targeted surveys of surface water and sediments …..delivered data that confirmed that this pathway does not contribute a significant dose to local communities" (p. 2). I have several concerns about the targeted surveys of water and sediments, which are presented later as well as in the Attachment for Appendix A4.

The basis for the estimate of 0.6 mSv/y is questionable. The only explanation for the estimate of 0.6 mSv/y is given in a figure in Section 7.8 (p. 44). The figure shows a total dose of about 5 mSv which includes gamma exposure as well as "land food", water, "aquatic food" and "land animal" and is based on the food survey average for adults and median gamma survey range. The estimated mine contribution is shown by an adjacent, smaller stacked bar graph which roughly corresponds to 0.6 mSv but which does not include gamma exposure. Accompanying text boxes state that that land, aquatic and land animal food sources all have "low probability for significant dose" and present bullet points in support of this statement. That is the extent of the explanation for the estimated incremental dose of 0.6 mSv/y.

The estimated incremental dose and the presence of high natural background radionuclide levels does not exempt QMM from using the ALARA principle. The use of the ALARA principle means that instead of assuming that there is still latitude for incremental mine-related contributions to total dose as long as incremental doses remain below 1 mSv/year, incremental exposures are kept to levels as far below 1 mSv/year as can reasonably be done, considering economic and technical factors. Since ALARA can have significant costs, the focus of actions should be management of the more important radiation sources and exposure pathways. Sources can include ore storage areas, spills, soil "hot spots", use of soils with elevated radionuclide levels for infrastructure such as roads or backfill, and mine water discharges (planned and unplanned). The report presents data which show that the exposure pathways which contribute the most to total dose are eating plants, fish and shellfish and gamma exposure. Management of these pathways could include: management of access to the mine site; on-site dust control; identification of and assistance with management of soils with particularly high radionuclide levels both on and off the mine site; and, treatment of mine water to remove the more mobile and soluble radionuclides prior to any discharge off-site.

Even if the Data Quality Objectives process had been followed more comprehensively, a specified quantitative level of confidence in the data may have required a high level of effort which was disproportionate to the risk associated with incremental radiation doses contributed by the mine. In such a case, the application of the ALARA principle introduces a level of precaution which can increase confidence that incremental doses will be acceptably low and do not contribute to exceedance of the regulatory limit for incremental radiation doses of1 mSv/year, or exceed the ICRP intervention level of 20 mSv/year.

The choice of where and how to apply the ALARA principle will depend on the relative benefit of actions taken to reduction of total dose and incremental mine-related dose. The level of confidence in both total (background plus mine) doses remaining below the ICRP intervention level of 20 mSv/y and incremental mine contribution remaining below 1 mSv/year cannot be established quantitatively. It may be determined that additional, targeted monitoring which is based on the complete DQO guidance is worth the effort if results help identify which alternative ALARA actions will result in the most effective and meaningful dose reductions.

Comments on "Findings of Note"

- "Radiation concentrations are highly variable and dominated by natural variations in soils"

  - This is true for gamma radiation but not for other measurements where variability is much lower than for gamma
    - Radon/thoron readings are consistently low
    - Water concentration variability is usually well within an order of magnitude and there are many results which are less than detection limits
    - Variation of radionuclide levels in dust depends on the radionuclide and the source (local dust versus long-range transport and deposition).
    - Variation among fish and shellfish samples is low
    - Variation among fruits, roots, grains and leafy vegetables is greater than for fish and shellfish and is dependent upon the radionuclide and the source (soil versus atmospheric deposition)
- “Eating land and aquatic based foods are (sic) the largest contributors to radiation dose”
  - This is true as long as gamma exposure is not included in total dose
  - There is no Appendix presenting details of dose calculations, so I have to take this finding at face value. However, given the results of the analysis of food items compared with results of radionuclide concentrations in dust and in water, it is a credible statement.
- “the food dose contribution varies according to the location and diet, with diet assumptions of each community being the dominate (sic) variable”
  - There is no Appendix presenting details of dose calculations and there is no reference to sensitivity analyses where different assumed consumption rates for specific food categories were used based on the different results from communities. Therefore, I can’t comment on this finding.
- “Although foods contribute a measurable dose, local food sources are safe from a radiological perspective”
- “Drinking water sources are safe from a radiological perspective”
- “Breathing the air (dust) is safe from a radiological perspective”
  - The ICRP uses precaution; i.e., erring on the side of safety, when they provide guidance such as 1 mSv/y for incremental doses above background and the “intervention level” of 20 mSv/year. In other words, guidance is deliberately kept well below doses shown to be associated with effects. The data in the report support the finding that total doses from eating local foods, drinking local water, and breathing in dust reflect the high natural background in the area plus a very small additional contribution from the mine and are below 20 mSv/year.
- “Mine surface water discharges are of a modest radionuclide concentration and are diluted by river volumes noting dilution will vary depending on river volumes”
  - Instead of using a vague adjective like “modest” to describe radionuclide levels in mine surface water discharges, it would have been preferable to simply describe the data. Radionuclide levels in mine waste water are elevated relative to baseline. The increases over baseline are small and well below drinking water guidance levels.
  - The evidence for the degree of dilution in the river is weak because of the lack of data from the river during times when wastewater is being discharged. I would just have acknowledged this and recommended that there be a ready-to-implement monitoring plan for when wastewater is discharged.

The final key finding in the Executive Summary is another unfortunate example of condescension bordering on insult. There are many potential causes of the persistent concern and anger associated with radiation, as I point out above. Ascribing the concern and anger solely to "misunderstanding and local myths" and hoping that "provision of these facts will assist in reducing local concerns" reveals a lack of understanding of the fundamentals of establishing relationships with communities. These fundamentals include transparency, accessible science, tangible benefits, open and inclusive dialogue, clarity regarding who is accountable, and consistent application of corporate and government policy.

Way Forward

I support the statements in the report regarding the way forward. These include "ongoing management of radiation at the Mandena mine must remain a focus of Rio Tinto, QMM and Government Regulators" (p. 2). The ALARA principle is invoked. Ongoing radiation monitoring is recommended - targeted to pathways requiring regular confirmation that radionuclide levels remain low as well as pathways which might be subject to future increases in radiation levels.

I also support the recommendation that future monitoring should involve regulators and local communities. Stakeholder involvement at all stages from design through communication of results has been shown to be effective in building trust and increasing mutual understanding.

The Executive Summary concludes by stating that it is "vitally important" that study findings and future monitoring results are "appropriately communicated with sufficient context, to the appropriate stakeholders, at regular intervals and in the appropriate format". I suggest that what constitutes "appropriate" includes the fundamentals of establishing relationships with communities which I list above.

Methodology

Strengths

The study methodology has several strengths. It starts with a thorough source-pathway-receptor conceptual model which documents all plausible linkages between radiation sources (natural and mine-related) and people. The conceptual model provided a solid basis for the collection of data needed to calculate total radiation doses from all relevant pathways.

Another strength is that many individual radionuclides from both the uranium and thorium decay chains were measured by alpha and gamma spectrometry. Unfortunately, the list of radionuclides analysed varied with sampling rounds and with types of samples (soil, sediment, water, food) and sample sizes were sometimes very low. However, at least some data were available for most radionuclides for most media.

It was helpful to see detailed field records and raw data from the analytical laboratories. This helped fill in some gaps in understanding; e.g., the type and amount of supporting data which were collected.

I note the specific efforts taken to achieve low detection limits through actions such as increasing the size (weight) of individual samples and creating composite samples. Detection limits have been an issue in previous work such as the SENES baseline and INSTN work on water and soils.

Gamma radiation measurements at the crossroads to examine exposure to trucks transporting rare earth concentrates as well as ilmenite and zirsill, while limited, are an important step in placing this potential pathway of exposure into perspective. I suggest that the study be repeated and dose implications updated if shipments increase in frequency and volume.

There was substantial effort devoted to dust collection and analysis. Collection of sufficient dust to allow for analysis of radionuclides is difficult and time-consuming, particularly under the conditions prevailing in the study area. Although the number of samples was limited, the data were valuable in terms of indicating the relative importance of the dust inhalation pathway.

The collection of food consumption data is a significant strength of the study. Food consumption surveys are difficult and rarely done, particularly with the sample sizes achieved in this study. Information on the alternative methods for dietary assessment and the rationale for the selection of the food frequency questionnaire approach was useful (Appendix A7, on pdf pg 686). -
The potential biases associated with the survey results were clearly identified in the report. Notwithstanding these potential biases, survey data from local residents is a great improvement over relying on information that is outdated and/or from locations that are not relevant to the social/cultural conditions in the Mandena region. Data from a total of 223 diet questionnaires representing six communities is a notable accomplishment (Appendix A7, Table 1 pdf p. 689). The report also provided details on food types, including edible mass (Appendix A7, Table 2, pdf p.691-692) which provided transparency regarding the basis for subsequent food intake amounts per food category.

The collection of food samples which represented primary food categories represents a primary contribution to furthering understanding of the role of the food ingestion pathway in the Mandena region. Considerable effort was devoted to collecting food samples while facing challenges caused by the COVID-19 pandemic. It is understandable that an iterative approach to the scope and scale of sample collection was necessary. It is also understandable that because of the almost complete lack of previous data on radionuclide levels in food, it was not possible to develop performance or acceptance criteria for food data (DQO Step 6).

Although an iterative approach to the collection of food samples was necessary, it produced results that have to be interpreted with caution, particularly with respect to comparison among sampling rounds. The adjustments to sample collection tools and practices, sample locations, sample weight requirements to achieve suitably low detection limits, laboratory analytical methods, and laboratory sample preparation procedures make comparisons among sampling rounds while contributing to greater quality control, created additional sources of uncertainty when interpreting the data.

I appreciated the comparisons of results with WHO guidelines and UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) reported ranges of background radiation levels. This allowed the reader to place radionuclide levels as well a radiation doses into perspective without having to search for guidelines every time.

The methods for calculating dose were appropriate. Average dose indicates the central tendency and is appropriate for cancer risks after long-term chronic exposure (US EPA 2006). Average radionuclide concentrations and average food consumption across communities in the study area were used. The assumption that land animals are not consumed is an accurate reflection of the diet of community members. Conservatism in dose calculations was provided by high assumed drinking water ingestion relative to WHO guidance and UNSCEAR data, and the use of whole-fish data to derive average radionuclide levels, the use of uncooked plant materials (cooking can remove a portion of some radionuclides).

There is a wealth of information in Appendix A8 regarding dose calculation which will be of interest to anyone tasked with similar calculations. Figures allowing quick comparison of concentrations per radionuclide per food type, annual dose per radionuclide per food type, and dose by age group and consumption profiles are provided.

Weaknesses

There were some notable weaknesses in the methodology. These weaknesses affect the level of confidence in the results and conclusions presented in the report.

There was usually no information on the timing of sampling, either in the main body of the report or in the Appendices. The only way to obtain the information would be a laborious review of individual field data sheets. Because of this, there was no easy way of determining the extent to which samples of various media were concurrent (e.g., concurrent dust and soil sampling; concurrent water, sediment, and fish sampling). If sampling is not concurrent, important influencing factors such as weather (wind speed and direction for dust and deposition to soils) or river flow (water and sediment quality) can confound data interpretation. Clear communication of sampling dates is also required for interpretation of the possible influence of seasonal or annual variation. These considerations are central to a confident review of the applicability of the overarching conclusions in the report.

Many of the weaknesses are associated with the water component of the study. This is unfortunate given that surface water pathways “had the highest potential for the greatest movement of mine generated radionuclides into the food chain and consequently the local community diet” (p. 51). A detailed examination of the weaknesses is presented in Attachment 4. Notable weaknesses include:

- None of the water sampling coincided with mine wastewater releases
- A different number of samples were taken during each of the 4 sampling rounds and none of the sampling rounds included all of the sampling sites identified in the design.
- No river flow or lake level measurements were taken. Flow and lake volume are driving factors determining radionuclide transport, chemical form, and concentrations.
- Supporting field data such as temperature, dissolved oxygen, electrical conductivity, pH and reduction/oxidation (redox) potential were not provided alongside radionuclide

results. These factors can have a strong influence on radionuclide levels in water and sediments.

- No replicates were taken at most sampling sites. Occasionally, duplicates were taken at one site only during a sampling round. Replication is a fundamental requirement if study objectives include comparison of within-site variability with between-site variability (e.g. upstream versus downstream).
- Each round included a smaller subset of samples analysed using gamma spectrometry to produce measurements of a more complete list of radionuclides. But the sites for which gamma spectrometry was applied varied with rounds.
- Because no 2 rounds were the same, comparisons among the 4 rounds for each site was not possible.
- An examination of consistency (or lack thereof) in radionuclides which were present above detection limits within categories might also have added useful evidence regarding whether there are particular radionuclides which are more frequently detectable on the mine site and/or downstream than upstream. Unfortunately, the lack of consistent use of gamma spectrometry means comparisons are still incomplete.

There were also several weaknesses in the additional round of sampling of water as well as sediments in order to collect information needed to estimate the effect of mine wastewater discharges on water and sediment quality in the MMM river. These weaknesses are discussed in detail in Attachment 4. Weaknesses included a very limited and cryptic explanation of how the estimates of dilution factors of about 90% in the MMM river were derived. Another weakness was the lack of any discussion of the substantial variation in texture among sediment samples, with the largest number of samples having coarse, sandy texture. This indicates that many samples may not have been depositional areas and so did not represent areas where insoluble radionuclides released in mine wastewater would accumulate.

The calculation of radiation dose used average radionuclide levels in dust, water and food (Appendix A8). The use of average radionuclide levels is appropriate for the overall population in the Mandena study area; however, it is not a precautionary choice when calculating dose for individuals whose day-to-day activities and lifestyle may result in exposure to an above-average combination of radionuclide levels in dust, water, and/or food.

It is unclear why the wood cutter scenario (which involved on-site gamma exposure) considered in Swanson (2019) was not substantiated. The report acknowledged that QMM has not succeeded in preventing people from collecting wood on the site. The report also noted that gamma exposure may be the most significant contributor to total dose (p. 43).

Data Quality Objectives

JBS&G state that the guidance from the Data Quality Objectives (DQO) process defined in the Australian Nation Environment Protection (Assessment of Site Contamination) Measure was used (report p. 32). The Australian process is based on the US EPA DQO guidance (US EPA 2006). "The DQO Process is used to establish performance or acceptance criteria, which serve as the basis for designing a plan for collecting data of sufficient quality and quantity to support the goals of a study. The DQO Process consists of seven iterative steps. ….the iterative nature of the DQO Process allows one or more of these steps to be revisited as more information on the problem is obtained." (US EPA 2006)

It was encouraging to see the list of DQO-related items on p. 32. The items correspond, in part, to the 7 steps of the DQO process.

However, after reviewing the report in detail, it was apparent that the DQO process was not applied fully or consistently across the various components of the study (gamma studies, radon/thoron, dust, water, sediments, soil, food). Because of this, uncertainty cannot be quantitatively characterized. *Thus, the likelihood that the following statement, which is one of the primary conclusions of the report, is correct cannot be determined* "these doses are as a result of naturally occurring radiation levels, with no evidence of significant contributions from mining activities being found" (p.2). It can only be evaluated by examining the available data at face value, combined with the professional judgment and experience of the reviewer.

The degree of concern associated with the inability to characterize uncertainty (the likelihood of being wrong) depends on the consequences of being wrong. Consequences will be highest in groups which are the most sensitive and/or the most exposed. How sure are we that the risk to the most exposed and the most sensitive groups (which may not be the same groups) is well enough understood that the use of the ICRP intervention level of 20 mSv/year and the regulatory limit of 1 mSv/year above the naturally occurring dose is sufficiently protective?

The baseline data and the data collected by JBS&G show that the population living in the study area is exposed to high natural background radiation. The data also show that background gamma radiation levels are highly variable, often within very small areas. Radionuclide concentrations in dust, soil, water, and food items are variable, but not to the same extent as gamma radiation. The JBS&G dose estimates indicate that 15 year-olds as the most exposed. Who within this group might have exposures which are above the average? Why? Where do they live relative to proximity to the mine and/or proximity to the most elevated natural background (e.g. black sands)? Are there other age groups where some individuals have higher exposures (e.g. woodcutters)?

Attachment 1 presents a work- through of requirements for each of the 7 steps of the DQO process with comparisons between those requirements and what was done in the study. Notable results for each step are presented below.

Step 1. State the Problem

- *Done*. "….an attempt to quantify the surrounding community member radiation doses from naturally occurring radioactive materials and any contribution from the decade plus of mining activities" (p. 1).
- Develop a conceptual model. *Done*. Section 6.2 of the report. (pp.20-24)
- Identify the intended use of the study data – Decision-making or Estimation. *Not clear.*

Step 2: Identify the Goal of the Study

- *Done, although the following quotes are not presented as goals*. "to determine the total effective radiation dose that local community members may receive" (p. 1). "To estimate the total effective dose, the cumulative dose from each source and each pathway will need to be considered in the assessment" (p. 21). These statements could be taken as the overall goal or purpose of the study
- Identify principal study questions.
    - *No explicit principal study questions for the study components except for surface and groundwater*
- Consider alternative outcomes or actions and develop decision statements or state what needs to be estimated and key assumptions
    - *The goal statements on pages 1 and 21 quoted above indicate that the intended use of the data was primarily estimation.*
    - *Key assumptions can sometimes be inferred from the study design but are not identified explicitly*

Step 3: Identify Information Inputs

- *Types and sources of information needed to produce estimates were not always explicitly identified so had to be Inferred from the description of sample sites and analytical methods*

Step 4: Define the Boundaries of the Study

- Define the target population of interest and its relevant spatial boundaries
    - *Spatial boundaries varied with study component (gamma radiation, radon/thoron, dust, water, sediment, food) which is understandable*
- Specify temporal boundaries and practical constraints
    - *The timing of sampling was unclear so it was difficult to determine whether the data could be used to evaluate seasonal or annual variability*
    - *Practical constraints were identified and actions taken to address them were described in the Appendices*
    - *The time frame for which the estimates (or, if applicable, decisions) are relevant was not explicitly stated.*
- *The scale of inference for estimation or decision-making was not explicitly stated nor discussed for the individual study components.*

Step 5: Develop the Analytic Approach

- Specify appropriate parameters for making decisions or estimates
    - *Averages were the most commonly used parameter, with occasional reference to medians, minima and maxima.*
    - *There were no depictions of data distributions; therefore, it is unknown whether distributions are normal, lognormal, bimodal etc. and percentiles were not determined nor presented*
- Choose an action level for decision problems
    - *The ICRP "intervention level" of 20 mSv/y and the regulatory limit of 1 mSv/y for incremental mine-related contributions to total dose were explicitly identified in*

- *the report, but it is unclear whether these are strictly to provide context for dose estimates or whether they are also intended to serve as action levels.*
  - *The EPA guidance suggests that an action level may be relevant to estimation problems if scientific studies or regulations specify a threshold value of exposure. The 1 mSv/y limit for incremental contribution to dose would qualify.* Average dose indicates the central tendency and is appropriate for cancer risks after long-term chronic exposure (US EPA 2006).
  - *There were no theoretical decision rules presented in the report ("if…then…else" statements)*
  - *There were no statements specifying the estimators. These had to be inferred from the report.*

Step 6: Specify Performance or Acceptance Criteria

- *This step was not performed.*
- *The report did not include decision rules and did not specify acceptable limits on estimation uncertainty*
  - Thus, there are no statements made regarding the level of confidence in the estimated total doses as well as estimated mine-related incremental doses.
  - In the absence of decision rules or statements of required confidence in estimates, qualitative narratives describing sources of uncertainty would have been helpful. Narrative statements regarding uncertainty were rare and did not accompany the overarching conclusions made in the report
    - E.g. "These dose levels are as a result of naturally occurring radiation levels, with no evidence of significant contributions from mining activities being found.".(page 2) The doses referred to are those from ingestion of food and water plus inhalation of dust. The statement does not acknowledge that there was only one baseline fish and one baseline crab sample and no other food data. Baseline water data were subject to high limits of detection for most radionuclides (typically above 1 Bq/L). The use of the phrase "significant contributions" implies statistical analysis. There were no data to support such analyses. The extremely limited baseline for water and food meant that quantitative decision rules or acceptable error limits could not be derived
    - Thus, a defensible qualitative narrative for this overarching statement is required. The narrative should clearly acknowledge the uncertainties associated with this statement as well as the consequences of being in error.
    - The narrative could include explicit consideration of specific critical groups such as woodcutters who are exposed to gamma radiation on site plus water, food and dust and 15 year-olds who live near or frequent black sands areas with higher gamma levels plus water, food and dust exposures.
  - Concentrations in the MMM River resulting from releases of mine water were inferred, not measured, because sampling took place during periods when releases were not taking place. There are no data to either support or reject these inferences from periods corresponding with releases.
- *Statements of confidence in the establishment of baseline statistics such as means, medians and percentiles must be based upon an understanding of fundamentals such as the distribution of baseline data*; i.e., whether the distribution is normal (bell-shaped) or not. If

the distribution of data is not normal, then a critical assumption underlying any parametric statistical analysis is violated and alternative statistical analysis methods must be used. *The report contained no statements regarding the distribution of baseline data. Therefore, there is no way of judging the validity and rigour of statements made regarding contributions of mining to total dose or the degree to which the incremental mine-related dose might approach or exceed 1 mSv/yr.*

- *There is also no way of quantifying the confidence that doses received by specific critical groups (e.g., 15 year-olds) would be unlikely to exceed the ICRP intervention level of 20 mSv/year*. In order to be able to make these evaluations, explicit tolerable decision error statements are required, as described in EPA (2006). For example, "we are 95% confident that 90% of doses to the critical group will fall below the ICRP intervention level".

Step 7: Develop the Detailed Plan for Obtaining Data

- *The study design was based on the judgement of the study team, rather than statistical inference*. Statistical inference requires a probability-based sampling design, as this type of design will allow you to properly characterize uncertainty. "Because the DQO Process is centered on properly dealing with uncertainty in your data, such designs are highly recommended as part of this process" (EPA 2006).
- Examples of common probability-based sampling approaches include simple random sampling, stratified sampling, and systematic and grid sampling. Probability-based sampling allows you to draw quantitative conclusions about the target population, while also properly expressing uncertainty in these conclusions through calculating confidence intervals, controlling for decision error probabilities, etc.
- "Judgmental sampling involves the selection of sampling units on the basis of expert knowledge or professional judgment. Emphasizing historical and physical knowledge of the underlying site condition and sampling units over the need to implement potentially complex statistical sampling theory make judgmental sampling an appealing option for some applications. However, judgmental sampling designs will not allow you to characterize uncertainty properly. As a result, the outcome of statistical analysis on data collected through judgmental sampling cannot be used to make any type of scientifically-defensible probabilistic statements about the target population. Conclusions are made solely on the basis of scientific judgment, and therefore, depend entirely on the validity and accuracy of this judgment." (US EPA 2006).

- There is reference in the report to "project data objectives", but these objectives are not always presented. In the DQO process, data objectives normally include the number of samples required to achieve a specified degree of confidence in the results. For example, it might be decided that the desired degree of confidence in being able to distinguish the incremental contribution of the mine operations to total dose is being able to correctly distinguish the mine contribution 70% of the time. In situations where there is high natural variability, a higher number of samples per location and more locations will be needed to be sufficiently sure that there are, or are not, differences between upwind and downwind of the site, or between upstream and downstream samples from the river.

Results – Direct Gamma Radiation Exposure

The report provides a useful summary of pre-mining baseline gamma radiation levels collected by SENES. The focus on measurements of gamma radiation reflects the opinion of SENES that the most important source of exposure in the study is external gamma radiation from soils containing elevated thorium concentrations (SENES 2001, p 38). Baseline gamma readings covered a wide range of less than 0.006 uSv/h on the Mandena mine site to greater than 4.8 uSv/h on the beach east of the then-proposed Ehoala MSP site. Gamma levels were higher over roads constructed with laterite and on black sand areas. The SENES report noted the uniformity of gamma radiation levels throughout the interior of the mine site (SENES 2001 p 11).

Follow-up studies by INSTN confirmed the general trends in the region. I agree with JBS&G's decision not to repeat region-wide gamma radiation surveys but instead to focus on specific pathways; i.e., wood collectors on the mine site and members of the public standing near the transport route or storage locations of rare earth concentrate or ilmenite/zirsill.

Wood cutting on the mine site continues and QMM has reported difficulties in managing woodcutter access. Notwithstanding this situation, JBS&G concluded that it was not necessary to determine a total dose to woodcutters because gamma dose rates were found to be reduced in areas that have been mined or after rehabilitation (p. 28). This reasoning may not be valid for areas of the mine site where mining has not yet occurred and there are remnant trees targeted by woodcutters. It would have been preferable to calculate gamma dose to woodcutters for comparison with dose estimates presented in Swanson (2019) using data for gamma radiation levels representative of unmined, mined and rehabilitated areas. In addition, total dose estimates for woodcutter exposure to gamma radiation, dust inhalation, and water and food ingestion would have addressed questions about whether sub-groups such as woodcutters receive total doses which differ from total doses for the general population. This information, in turn, would indicate whether additional mitigation measures are needed as per the ALARA principle.

Some issues with the gamma measurement pre and post-mining presented in Appendix A1 are noted and discussed in Attachment 2. The new data presented in Appendix A1 are insufficient to support the overall conclusion statements regarding pre and post-mining dose rates. The study design was judgement-based rather than based on statistical inference. The pre and post-mining study design was limited to one area near the buffer zone adjacent to Lake Ambavarano. Only one true transect was established. Replicate gamma readings were not reported – a concern given how variable gamma readings can be within a short distance. There was no discussion of the rehabilitation methods, including how recently the area had been rehabilitated.

Studies of doses from exposure to rare earth, ilmenite and zirsill transport encountered challenges caused by theft of monitors which limited the amount of data which could be gathered. Doses were very low, declining rapidly with distance from the truck surface. However, the data are very limited, with only one valid measurement campaign. I would suggest that the measurements need to be repeated, including at least two replicates per sample location since the variability for the duplicates on the north and south side of the road are right at the 15% tolerance reported by the manufacturer of the dosimeter devices. The variability of background doses also needs to be established. Additional comments are provided in Attachment 2.

JBS&G took what were described as "ad hoc" gamma measurements in villages in 2019, and dose rates fell within the SENES baseline range for the Mandena area (which was lower than Fort Dauphin, Port of Ehoala and Evatraha areas). Measurements were also within the range of measurements done by INSTN in 2014.

Table 2 of Appendix A1 (pdf page 71 of 2111) presents a summary of the 1000s of SENES baseline gamma measurements. A data distribution would have been very useful in terms of enabling a statistical inference-based design (per DQO guidance) for the pre and post mining study as well as the transport study. The data distribution would have also allowed a visual assessment of where the new gamma data fits within the distribution. This is particularly relevant to understanding the likelihood of gamma exposure to sub-groups such as woodcutters and 15 year-olds who might frequent black sand areas producing total doses which might approach or exceed the 20 mSv/y ICRP intervention level.

Results – Radon/Thoron Inhalation

Radon and thoron measurements were very low, as expected based on baseline data, INSTN data from 2017 and Swanson (2019). There were no surprises in the results, which reflected well-ventilated spaces typical of the region.

Doses from radon/thoron exposure were not calculated because levels were below the WHO residential reference level of 100 Bq/m^3. Levels were within typical background ranges.

Results are in agreement with Swanson (2019) where it was concluded that it is highly unlikely that any monitoring system would be able to discriminate the extremely small additional exposure from the mine from variable natural exposure.

I note that more enclosed buildings with less ventilation such as offices or hotels may have higher radon/thoron levels, as found during the INSTN study. In that study, an off-site hotel and a QMM employee residence had mean Rn levels of 70 Bq/m3 and 32 Bq/m3 respectively. However, these levels are still below the WHO reference level.

Results – Dust Inhalation

The collection of dust data at 2 upwind, 4 downwind and 1 crosswind/downwind dust locations provided important information with which to assess the relative contribution of dust inhalation to total dose. The choice of site location was governed by prevailing wind direction. The rationale for the number of stations was not provided in the report. This is an example of "judgement-based" study design rather than "statistical inference" design. Thus, the degree of confidence in the data cannot be quantitatively established.

Interpretation of dust deposition vs dust concentration in air results is limited to a qualitative narrative. The dust deposition results are described as "generally consistent with the dust concentrations in air" (Appendix A3, page 125/2111). There is no statistical analysis (e.g. regression of concentration against deposition). The number of individual measurements per station used to calculate average dust concentrations per particle size category is not reported. The "average" dust deposition rates in Table 3 were presumably calculated from two measurements – one of total dust collected from deployment 1 and one of total dust collected from deployment 2. However, the averages could also have been calculated from analysis of dust from individual retrievals of the contents of gauges (which apparently could be as frequent as weekly due to high rainfall). In any case, standard deviations are not presented in Tables 2 (Appendix A3, pdf p. 125/2111) and 3 (Appendix A3, pdf p. 26/2111. Furthermore, as far as I can determine, duplicate gauges were not set up at any of the stations.

Interpretation of radionuclide results is also limited to a qualitative narrative. The means and standard deviations in Table 4 (Appendix A3, pdf p. 127-128) and Table 5 (pdf p. 128-129/2111) are based on 2 samples per station (1 per deployment presumably consisting of a composite of retrieved samples from each gauge over the deployment period). Presentation of means and standard deviations derived from only 2 data points per station is not warranted and could be misleading. It would be preferable to present the results for each of the 2 samples per station.

Comments on the summary description of results:

"Breathing in dust across the region has a very small radiation dose of 0.07 mSv/year. (pdf p. 37/2111).

> This statement is based on 2 samples per station. It is good to finally have data on radionuclide concentrations in dust. And the results indicate that dust is probably not a major contributor to total dose. But the level of confidence in this statement would increase had there been an ability to compare within-station and between-station results via the deployment of at least 3 replicate gauges located at a minimum of one upwind and one downwind station.

"Maximum possible dust contribution for the mine site is less than the total dose of 0.07 mSv and estimated to be 0.02 mSv using a downwind/upwind subtraction method." (p. 30)

> The data are not sufficient to claim that a maximum possible dust contribution for the mine site is known. Two samples each from 2 upwind and 4 downwind sites is a small dataset – albeit a welcome start.

Results – Drinking Water

As with all other study components, the water study design was judgement-based. Determining the incremental contribution of the mine to radionuclide levels and doses was one of the two overall study goals. Water was identified as the most significant pathway leading from the mine. Dust contributions were described as "minor" (p. 31). Given the importance of understanding the relative contribution of the mine to total dose, it is disappointing that the study design did not use statistical inference-based approach. There were existing data from QMM monitoring programs and other sources which could have been used to evaluate upstream and downstream variability and then calculate the sampling effort required to distinguish the mine contribution from natural background at various confidence levels.

The report frequently refers to "large natural variability" spatially and temporally in the context of how difficult it can be to distinguish mine contributions from natural radioactivity levels.

"Large variations in NORM mean that 'control', 'background' or in this case 'upstream' locations could naturally be higher or lower than 'downstream' of the mine and thus deliver an erroneous result when 'background is subtracted' to determine the mine increment" (p 32). "Radionuclide sampling results demonstrate a large natural variation, masking any potential mine site contribution" pdf page 42. While true when discussing all results collectively, examination of water data in Appendix A4, as well as the depiction of the range of results for Po210, Ra226 and Ra228 in the figure in section 7.3 (p. 32), reveals that variability is not particularly large. Thus, it should have been possible to develop a design that made a start towards the use of statistical inference.

The contribution to total dose from specific radionuclides which may be an indicator of the mine waste water such as Ra226 and Th 228 might be informative– these two radionuclides have levels considerably higher in the wetland area than other radionuclides. Conditions in the wetland are of particular interest since it is adjacent to the MMM River.

The report states that "Average Ra226 concentrations can be used for comparison as they are typically measured values. These are similar in upgradient and downgradient sample. Po210 concentrations are also comparable between background areas and samples collected close to critical groups and within the range of typical drinking water" (pdf p. 176). I assembled Table 1 for Ra226 data from all 4 rounds as a check on this statement.

Table 1 Ra226 Levels from the Four Rounds of Water Sampling. Bq/L. [Data from Appendix A4]

Round	U/S SW	U/G GW	D/S SW	D/G GW	Mine Site SW	Mine Site GW
1 12 of 15 SW sites sampled. (Table 3). 6 of 8 GW sites sampled (Table 5)	Table 3 0.001-0.011* Mean 0.006 N=4 *anomaly ?	Table 5 0.0024-0.0044 Mean 0.003 N=2	Table 3 0.005-0.014 Mean 0.006 N=9 (SW07 had duplicate samples	No Data	Table 5 0.083 N=1	Table 5 0.17-0.42 Mean 0.296 N=5 (duplicates for one site)
Gamma Spec Subset	No Data	No Data	Table 4 0.002-0.009 Mean 0.006 N=4	No Data	No Data	No Data

2 6 of 15 SW sites sampled (Tables 6 and 7); 6 of 8 GS sites samples (Tables 6 and 7)	Table 6 0.0004-0.0009 Mean 0.0007 N=3	Table 6 0.0005-<0.001 Mean 0.0008 N=3 (duplicates for one site)	Tables 7 (SW07,08) and 8 (SW 05, 07, 09, 10) (SW07 and 08 adjacent to discharge in MMM River) 0.0005-0.0014 Mean 0.001 N=7	No Data	Table 7 (SW01) 0.015 N=1 SW01 is Ambondrombe pond between mine lease and MMM River	Table 7 0.02-0.16 Mean 0.077 N=4
Gamma Spec Subset	No Data	No Data	Table 9 0.0006-0.0049 Mean 0.002 N=4	Table 9 0.0029 N=1	No Data	No Data
3 13 SW sites sampled with 2 new sites (SW16 and SW17) (Tables 10,11,12) 2 of 6 GW sites sampled (Tables 10-12).	Table 10 <0.001-0.0012 Mean 0.001 N=3	Table 10 0.0009 N=1	Table 12 0.0013-0.0054 Mean 0.0023 N=4	No Data	Table 11 (for SW01 Ambondrombe pond and SW 16 17) 0.0043-0.0850 Mean 0.042 N=3	Table 11 0.022 N=1

Gamma Spec Subset	No Data	No Data	Table 13 0.0004-0.002- Mean 0.0012 N=4	Table 13 0.0008 N=1	No Data	No Data
4 11 of 15 SW sites sampled (Tables 14 and 16. 3 of 8 GW sites sampled Table 15)	Table 14 <0.002-0.0044 Mean 0.002 N=4	No Data	Table 16 SW04-8 and SW10. 0.0004-0.0029 Mean 0.001 (SW07 had duplicate samples) N=7	No Data	Table 16 Sample SW01 from Ambondrombe pond on the mine lease. 0.006. N=1	Table 15 0.034-0.37 Mean 0.131 N=5 Duplicates at GW04 and GW05)
Gamma Spec Subset	No Data	Table 17 <0.002 N=1	Table 17 <0.002-0.0029 Mean 0.003 N=5	No Data	No Data	No Data

Sample sizes were usually low and there was no replication within sampling stations (with the exception of duplicates taken at SW07). Sample sizes were often not the same among sampling rounds, or no samples were taken within a category at all. These issues preclude any attempt at statistical analysis. However, mean Ra226 levels in red font indicate cases where there may be differences between upstream and downstream levels. The mean Ra226 levels in blue font indicate where there is a slight indication of differences when the range of results are compared.

Attachment 4 identifies several other issues associated with the water sampling methods and reporting of results. These issues made it difficult and frustrating when trying to work with and understand the results.

Water contribution to total dose

"Drinking water across the region has low radiation levels, with a total dose of 0.06 mSv/y and at least an order of magnitude below WHO guidelines for all radionuclides analysed (radiological and chemical properties considered)." Pdf page 39.

I appreciate the effort taken to obtain sufficient sample volumes for low detection limits and thus provide data which support suitable resolution in dose assessments. There is still noticeable variability in detection limits among sampling sites and sampling rounds. But this does not affect the overall conclusion that radionuclide levels and total doses from drinking water are low and well below guidance levels (see Attachment 5).

The figure on pdf page 39 (report page 32) is provided as support for the conclusion that water contributes a small portion of total dose. The figure presents results for a total of 73 samples for three radionuclides – Po210, Ra226, and Ra228. The results for these three radionuclides are well below WHO guidance levels for drinking water. The figure includes a bar graph depicting dose from water ingestion for adults and most sensitive people (e.g., infants). These doses are well below the public dose limit of 1 mSv/year. The "error bars" on the doses in the figure are not explained but presumably represent minimum and maximum.

Attachment 4 contains additional comments regarding the presentation of data regarding water contribution to total dose. I note that I was unable to confirm the total of 73 samples depicted in the figure from information in Appendix A4.

Visual examination of the data in Appendix A4 indicates that drinking water is not a major pathway contributing to total dose. Most individual radionuclide measurements were very low – often below detection limits (as illustrated by the data in Appendix A4). Only a few radionuclides were present in amounts above detection limits and those results were still very low and well within what would be expected in an area with high natural background levels of radiation.

A statistically-based quantification of the degree of confidence associated with the data is not possible. This is because of numerous limitations in the study design itself as well as the implementation of the design and analysis of the results.

Mine-related contribution to total dose via water

Conclusions drawn in the report regarding the incremental contribution of the mine to radionuclide levels downstream of mine discharge relied, in part, on an additional round of sampling of sites within the mine waste water network and at the point of release to the MMM River. This sampling was conducted because discharge of waste water from the mine had not occurred before or during the previous 4 rounds of sampling. Thus, there was no opportunity to compare radionuclide levels at the point of discharge with levels at increasing distances from the discharge within the same time period as the discharge occurring. Instead, the conclusion that mine contribution would be very small and within baseline variability is based upon estimates of dilution factors of about 90% in the river from data collected "intermittently" over a three-month period in 2022 as well as comparison with baseline data collected by SENES for Pb210, Th228 and Ra228 (pdf page 40, report page 33).

The reliability of the estimated dilution factor in the river is unknown. There are no details provided regarding the data collected intermittently in 2022. There is no mention of where the

samples were taken, and no explanation of how they were used to estimate the dilution in the river.
The report states that "…all waters within release and decantation ponds and all waters outside of the mine perimeter returned concentrations within baseline LODs (limits of detection) and within the range of radionuclides measured in the baseline survey (Pb210, up to 13 Bg/L, Th228 up to 0.7 Bq/L, and Ra228 up to 2.4 Bq/L" Appendix A4 pdf page 182). It is not difficult to be "within baseline LODs" since those LODs are very high relative to the LODs in the JBS&G study. The point is whether the measured radionuclides on the mine site in the JBS&G study are consistent with JBS&G upstream levels – and they are not. They are substantially above upstream levels as well as downstream levels.

"Mine discharge enters a significant wetland area prior to the MMM River, which would further filter any elevated radionuclides attached to sediment" pdf page 41. Which radionuclides attach to sediment and which are more prone to remain in the water column? Would resuspension occur during flood events? Are there plans for deployment of targeted monitoring immediately following a release due to flood events? Have there been or are there plans for a focussed study on the efficacy of the wetland area for removal of radionuclides and other contaminants of concern, notably metals such as aluminium and lead?

The evidence presented in the report regarding mine contributions to radionuclide levels in the river is weak. It will be important to have a ready-to-implement study plan for sampling water at the discharge and at defined distances downstream when the next wastewater discharge occurs. There are well established methods for defining mixing zones and estimating dilution factors. These methods should be referenced and used to inform the study plan. The study plan should address the following questions. Are there discharges already planned? What about discharges required due to flood events? Is there a ready-to-implement sampling plan for the next wastewater discharge? For water, sediment and fish/shellfish? Should irrigation water be sampled during the next wastewater discharge period? For which crops?

It would also have been very helpful to have a chronology of past wastewater discharges included in the report.

Results – Soils and Sediments

There was very limited soil sampling in this study during "Round 1" in December, 2019. This is one of the few times that the time of sampling was identified without having to delve into field data sheets. Five samples were taken at locations where selected food types were grown (rice, cassava, banana, and pineapple). It is not clear why these samples were taken, apart from a cursory check against the baseline data from 2000 or perhaps to obtain a bit more data on variability among radionuclides and with sample site. Measurable U238, Ra226, Pb210, Th232, Ra228, Th228 and K40 were reported (Table 2 of Appendix A5, pdf p 319). Variability among sites was low for all radionuclides. U238 and K40 levels were within UNSCEAR ranges.

Soil sampling conducted with sufficient effort to verify uptake factors from soil to plantsin the Mandena region would have provided useful new information.

Sediments were sampled during Rounds 1 and 5. Round 1 sampling was limited to three "representative" river and lake sediments where community members from Mandromondromotra, Andrakaraka and Emanaka interact with the sediments through fishing or swimming. Round 5 sampling was done to assess whether radionuclide levels in sediment indicated incremental accumulation downstream of past mine wastewater discharges.

The JBS&G discussion of soil and sediment data from round 1 included comparison of averages calculated from all samples – whether soil or sediment with concentrations in soils published by UNSCEAR and IAEA. This is not valid since soil and sediment represent different pathways in the conceptual model with different relative roles of fate and transport processes. The Round 1 results are described as being within the range of measurements conducted during baseline surveys (pdf p.320). Compiling baseline ranges of U238, Th230, Ra226, Pb210 and Ra228 levels and comparing them with ranges from Rounds 1 and 5 confirmed this statement (see Attachment 5).

Sediment data from Round 5 were used in support of the assertion that the mine contribution to radionuclide levels and to dose from water ingestion is very low. The report concluded that thorium and uranium levels were within the range of natural variability when comparing mine site and MMM River samples with upstream sediments and baseline values, and that "there was no evidence of Ra226 or Ra228 enhancement in downstream sediments" (pdf page 40, report page 33). This statement was based on U238:Ra226 and Th232:Ra228 ratios averaging about 1.0 "when considering uncertainties" (pdf page 328).

Table 2 presents side-by-side comparisons of Round 5 results for uranium and thorium with SENES baseline data from sites near the Round 5 sites. A site downstream of Lake Besaroy in the Meander River also showed higher uranium and thorium than baseline (indicated by yellow highlights). However, the differences are not large enough to be sure given the small number of samples and no field replications. Furthermore, SENES did not report sediment texture, which can significantly influence radionuclide concentrations. However, the data in Table 3 cast some doubt on the conclusion that uranium and thorium levels in downstream sediments are within the range of natural variability of upstream sediments and baseline values.

Table 2. Comparison of Baseline and Round 5 Sediment Uranium and Thorium Levels at Sites Located Near Each Other.

SENES Baseline Sampling Station	Round 5 Sampling Station	U SENES	U JBS&G	Th SENES	Th JBS&G
29 Lake Ambavarano	SD5 Lake Ambavarano	14.3	9.4-10.3	262	185-202
32, 33 Near Mouth of MMM River	SD6 MMM River u/s of discharge to Lake Ambavarano	4; 3.4	Not analysed	44.1;33.6	Not analysed
30 Upstream MMM near mine	SD11 and SD 12 near mine discharge points	7.6	9.8-12.6;3.7-8.5	55.1	123-124;38.7-102
31 Midpoint MMM near mine	SD 8 SD9 SD10 Adjacent to discharge	2.8	3.9-23.5; 3.0-3.9;	13.9	41.6-294;30.4-

	points from the mine		4.8-13.5		44.2; 27.3-205
28. Downstream of Lake Besaroy described as “narrow river channel”	SD2 Lake Besaroy	3.4	6.9	59.2	146

Uncertainties associated with sediment results include a substantial variation in sediment texture, which ranges from “gravels and very coarse sand through to organic rich silts and clays” (pdf page 328 and Table 7 pdf page 328-329). This is a very important source of uncertainty since adsorption of radionuclides will be much higher in fine-textured sediments such as clay and silt than in coarser sediments such as sand.

Sand was the dominant texture found among sample sites, which would be expected since this is a mineral sand region (see Attachment 5). Finer-texture silts were found at some locations on the mine site, including settling ponds, and in Lake Ambavarano and Lake Besaroy. This would also be expected since non-flowing pond or lake areas allow for finer particles to settle out and accumulate. There were different textures in duplicates taken at four of the MMM River sites, indicating that sediment texture can vary over a short distance in river environments.

Adsorption of radionuclides to sediments is influenced by a number of factors, including but not limited to sediment texture; therefore, it is site-specific (Juranova et al. 2020, Bezuidenhout 2020). Other factors influencing radionuclide interaction with sediments include water temperature, redox potential at the sediment/water interface, and the presence of other chemicals in the water or sediment which could provide alternate adsorption surfaces or chemically interact to produce different chemical forms (also called species) of radionuclides. There can also be gradients of radionuclide concentrations from upstream to downstream, which are influenced by watershed geology, hydrology, and human activity (Jibiri and Okeyode 2011, Bezuidenhout 2023).

Results – Food Consumption: Rice and Grains, Root Vegetables, Leafy Vegetables, Fruits, Fish and Shrimps

The iterative nature of the food study makes comparison of results among the four sample rounds difficult, as noted in my comments on methodology above. Analytical methods varied with sample round, as did the range of food categories (Table 3 of Appendix A6, pdf p. 362). Sample sizes per food category were low among rounds and among sample locations. All Round 1 fish results had to be eliminated from the dose assessment because of “major uncertainties” regarding fishing locations and the possible contamination of shrimp samples which were dried on mats on the ground (pdf p. 364).

Plants

The food data appear to have been used primarily to produce average radionuclide concentrations for use in calculation of dose. I did not find any exploration or interpretation of the range of results among sampling rounds/seasons, food categories, sample locations (villages) in Appendix A6, apart from comparison of results with reported ranges and UNSCEAR reference values (Table 13, pdf p. 374; Table 24, pdf p. 383). Radionuclide levels were commonly above UNSCEAR reference levels but within UNSCEAR ranges except for U238 in one rice sample (Table 15 pdf p 383). Since the UNSCEAR database is very limited, comparisons should be made with caution. There was also some discussion of results for cassava leaves, which had relatively high concentrations of Po210 compared to other radionuclides (pdf p. 383). This was attributed to wet and dry deposition.

Some initial exploratory qualitative assessment of the food data would have added value. For example, the report states that "Sampling was undertaken seasonally in an attempt to capture any significant variation in diet consumption" pdf page 41. Did the data capture this important consideration?

Round 4 appears to be one of the few opportunities to compare results among samples of the same plant from one site (Cassava root in Ampasy) (Table 22 pdf page 381). A brief review indicated that radionuclide levels were relatively consistent from sample to sample except Th230.

Round 4 also had the largest number of different types of fruit as well as Cassava leaves and manioc root. The variability of radionuclide levels among samples in Round 4 was not pronounced; i.e., differences in levels were within the same order of magnitude (Tables 21-23, pdf p.381-382).

Ideally, comparisons of radionuclide levels in plants would be made among communities. However, the location of plant samples was not always noted in data tables, and sample sizes were too low to allow for much, if any, among-community comparison.

The report states that "all plant samples show a high variability of radionuclide concentration" (pdf p. 383). The data in Appendix A6 do not support this statement. Variability within and between plant types is within the same order of magnitude in all sampling rounds. The variability in Tables 14-23 (p. 374-383) is commensurate with the expected variability associated with factors such as time of sampling, age of the plant, and different uptake processes and rates among roots, leaves, and fruits.

Additional context for the food data would have also added value. For example, the report states "There is limited irrigation in the region due to high rainfall" (pdf p. 41. What is the evidence in support of this statement? There has been drought in the region, does irrigation occur during droughts? Where? For which crops? Answering these questions is important in order to identify whether there should be additional monitoring focussed mine-related incremental contributions to radionuclide movement off-site and into food chains. This is particularly true for times when mine wastewater is discharged.

Discussion of the soil context for the plant data was minimal. As noted above, five soil samples were taken (corresponding with rice, cassava, banana, and pineapple samples). Radionuclide levels were above detection limits except Th230 and levels were within worldwide ranges. Variability was low among sites. There were no supporting soil data such as texture, organic content, soil moisture. Replicates were not taken; therefore, there is no information on within-site versus among-site variability.

The report states that “local variability in soil radiation is high at distances as low as metres” (pdf p. 41). When explaining total dose results, the report notes that “radiation concentrations are highly variable and dominated by natural variations in soil” (p 43). When discussing results for fish and shrimp, the report once again describes radionuclides in soil, sediments and water as “high variable”; and commenting that fish and shrimp may therefore move from low-concentration to a high-concentration areas (p. 45). These statements are misleading. Gamma radiation levels can vary greatly over short distances (as illustrated by the SENES baseline). But results for individual alpha and beta-emitting radionuclides in soil and in water (which are the most relevant to internal dose to ingestion) are not nearly as variable, as noted in the foregoing paragraph and in discussion of water results above.

Fish, Shrimps and Prawns

Fish samples were composites of 2-5 species. Sample sizes varied across the study area, with the largest number of samples taken from various locations in the MMM River.
Fish were from lake, river and pond habitats. Because fish are mobile, fish captured upstream of the mine are not necessarily representative of “background”. JBS&G notes that species and number of specimens depended on the fishing location and sample sizes varies significantly across the study area. This made it difficult to make comparisons among sample locations (pdf p. 374).

Examination of results for Rounds 2-4 (Tables 6, 8 pdf p. 367, and 11 pdf p.372) showed that variability among results was often driven by 1 or 2 samples which were less than detection limits when all the other samples were detectable. This may reflect difficulties in sample preparation, sample size, or variability in the species making up the composite sample. Results which were detectable did not have notably high variability; i.e., variation was within an order of magnitude. I do not interpret variability of less than an order of magnitude to be particularly noteworthy when dealing with composite fish samples of unknown size and age distribution comprised of from 2-5 different species.

I noted with interest the Th232, Ra228 and Th228 levels, which were consistently detectable and the highest levels of all measurable radionuclides. These radionuclides have similar levels at most sampling locations; e.g., mine site rehabilitation pond, upstream, the mine discharge point downstream in the MMM River and in Western Lake (Table 11, pdf p. 372). Data for thorium series radionuclides in fish is very rare. The data from this study makes an important contribution.

Radionuclide levels in shrimp were similar to levels in fish. The thorium-series radionuclides were also among the highest measured levels, as they were for fish (Tables 6 pdf p. 367 and 9 pdf p. 369).

“Radionuclide concentrations and ratios between radioisotopes are highly variable.” (pdf p. 374). This variability was attributed to factors such as the difficulties of sample homogenization as well as differences between alpha and gamma spectrometry results. As discussed above, I do not consider the variability among measurable radionuclide levels to be particularly noteworthy and would not describe it as "high". High variability is what you see with gamma radiation measurements in the study area. Fish radionuclide variability is not in the same league.

"Fish products typically returned concentrations within reported ranges, but above UNSCEAR reference values (see Table 13)" (pdf p. 374). I agree that because the composite samples were of whole fish while the UNSCEAR data are typically for edible portions of fish products with bones, shells, and viscera removed, comparisons need to be made with care.

Doses

Dose from plants and fruit

"Across all communities, eating plants and fruit results in a moderate radiation dose but within expected averages of mineral sands regions globally" (p. 35). What does "moderate radiation dose" mean? Relative to other pathways of exposure? Relative to average doses from plants and fruit ingestion in mineral sands regions globally? [If this is the case, a comment on the scarcity of data on food ingestion pathways would be warranted – especially for countries like Madagascar – or anywhere in Africa for that matter].

Two definitive statements are made in the report regarding dust and incremental dose from QMM operations due to wet and dry deposition. "Fugitive dust has been eliminated as a significant contributor to the dose pathway with the local soils having a far greater influence" (p.35). "Relatively elevated Po210 concentration in leaves indicate that dry and et deposition is a significant contributor to dose. However, an incremental dose from QMM operations cannot be identified and dry and wet deposition can be eliminated as a significant contributor to the dose pathway" (p. 35).

The data do not provide sufficient support for such definitive statements. While I agree that radionuclide levels in dust were very low, sample sizes for both dust and soil are also very low. There were only two upwind/ downwind samples of Cassava leaves (Tables 19 and 21, pdf 379 and 381). More data are needed, particularly to allow comparison between Po210 levels via local dust deposition and longer-range atmospheric transport and deposition.

Two statements are made regarding incremental mine contribution to radionuclide levels and dose. "Radionuclide sampling results demonstrate a large natural variation, masking any potential mine site contribution" (p. 35). "The pathway from QMM operations to crops via surface water is considered a negligible increase due to moderate discharge concentrations, infrequent discharges, wetland filtering of mine discharges, river flow dilution factors and limited irrigation practices" (p. 35).

The data do not support either of these statements. I have already provided comments on the actual range of variation in plant samples above, which I would view as low. I have also provided comments on the shortcomings of both the methodology and the findings of the Round

5 water and sediment sampling done to estimate river flow dilution and identify whether mine-related sediment deposition has occurred. There are insufficient data from the wetland area and no data to substantiate the claim that irrigation is limited. Attachment 4 provides additional detailed comments. The only part of the statement that can be agreed with is that mine wastewater discharges are infrequent. It is fortunate that discharges are now infrequent. However, flood-related discharges still occur and the future frequency and nature of discharges is unknown. There is no information provided in the report regarding whether the water treatment plant on the mine site might also remove radionuclides as other constituents of concern such as aluminium are removed.

Dose from fish and shrimp

Dose from eating fish and shrimp was described as "moderate" and within the reported range globally (p. 37). These doses are a significant contributor to total dose.

Incremental contribution of mine water discharges to fish and shrimp doses is considered to be negligible (p.38). This conclusion relies upon "measured indicative dilution factors" which are not provided in the report but only referred to accompanied by an overall estimate of 90% dilution. The shortcomings of the sampling and interpretation related to this conclusion have already been identified above and in Attachment 4.

Results – Total Dose

Total annual effective doses to all age groups (ranging from infants to adults) were as predicted by JBS&G; i.e., "elevated when compared to global background averages, but similar to other mineral sands provinces around the world" (p. 41). Highest annual doses from dust inhalation, drinking water, and eating plant-based foods, fish and shrimp were 12.2 ± 2mSv/y for 15 year-olds living in Andrakaraka (Table 8. P. 41 and Appendix A8 Table 2. Pdf p. 2041).

Doses calculated using food consumption profiles from UNSCEAR and WHO were presented alongside doses calculated using food survey results from the Mandena study area (Table 8, p. 41). The reason given for doing this was that "the level of consumption from the food survey is likely overestimated as in most cases, it exceeds the WHO levels" (pdf. p. 2041). JBS&G provided an example for one community (Andrakaraka) in Appendix 7, based on anecdotal evidence from a discussion with the QMM local medical doctor that fish and shrimp were sold rather than eaten (pdf p. 690). Other evidence included the lower overall number of families reporting protein in their daily diet compared to fruits, leaves and grain (see Attachment 3 of Appendix A7 pdf p.2024 -2036). JBS&G also discussed the challenge of removing fish from the catch of local fishers because the loss of protein from diets "is a current and real health issue" (p. 44).

The subtext for presenting doses calculated using WHO consumption levels is that actual doses to people in the Mandena study area are probably lower than calculated because of the "exaggerated" consumption reported in questionnaires. This subtext is explicit in the Executive Summary where it is pointed out that "an alternative food consumption profile (WHO Africa) would result in a dose estimate of 1.0 mSv/year" (p.1). [Later in the report, the dose using WHO

(Africa) consumption for 15 year-olds is given as 4.7 ± 1.0 mSv/y (Table 8, p. 41).] The evidence for exaggeration is limited and pertains only to protein (fish and shrimp). Alternative explanations include limitations and biases of the WHO data, and region-specific consumption patterns which are different than country-wide or continent-wide patterns that represent a combination of rural and urban data and subsistence vs non-subsistence lifestyles. Another alternative explanation is that in a subsistence economy, the geographical location of individual communities affects consumption patterns. There is evidence of this in the Mandena region. Andrakaraka is close to the mouth of the MMM River, Lake Besaroy, Lake Ambavarano and is adjacent to the Baie De Fardofay. Thus, it is close to marine, estuarine, and freshwater fishing areas. It would be expected that fish and shrimp would be a more common part of the diet in Andrakaraka (with average fish consumption of 63.39 kg) than in communities such as Ampasy and Betaligny which are inland and not located on or near lakes (with fish consumption of 23.54 kg and 25.61 kg, respectively) (Table 2, pdf p. 2041). Inland villages in close proximity to crops and fruits, might be expected to have higher consumption of fruits and leaves, and the data in Table 2 confirms this. Grain (primarily rice) consumption is consistent across communities in Table 2.

The use of average radionuclide levels is appropriate for the overall population in the Mandena study area; however, it is not a precautionary choice when calculating dose for individuals whose day-to-day activities and lifestyle may result in exposure to an above-average combination of radionuclide levels. The "critical group" (15 year-olds living in Adrakaraka) were estimated to receive the highest annual radiation dose from ingestion (food and water) and inhalation of dust at 12.2 ± 2 mSv/yr. The ICRP suggests that doses less than 20 mSv/yr do not justify intervention. But what is the level of confidence that this dose is not an underestimated? The report would be strengthened by presenting evidence for the level of confidence in calculated doses. Are there scenarios where annual doses could approach or exceed 20 mSv/year? For example, a 15 year-old boy who helps family members with wood cutting on the QMM site and with tending fields (where soil ingestion may become relevant), spends time with friends near dusty roads and on playing fields (possibly with higher exposure to dust), eats larger portions of land and aquatic-based foods than the average, regularly swims in the river, and drinks water directly from rivers and lakes might have a higher dose than his peers.

JBS&G point out that external gamma exposure must be considered when establishing total annual dose (p. 42). Figure 16 on page 42 provides gamma radiation dose ranges superimposed on the annual dose from dust inhalation and water/food ingestion. Median gamma levels would have the potential to increase annual doses to above the ICRP intervention level of 20 mSv/y, depending on gamma exposure frequency and duration. Despite this observation, there is minimal discussion of this figure. The only statement is that external gamma radiation may, in places, "be the most significant contributor to overall dose". There is no discussion of where the individual communities used for the dose calculations might fit within the wide range of gamma radiation levels. This is an important question because the baseline gamma data are primarily for the mine site itself and the Fort Dauphin, Ehoala and Evatraha areas. Therefore, community-specific gamma radiation measurements might be needed.

In addition to the potential importance of gamma radiation exposure, JBS&G list the following findings of note (p. 43):

- "Radiation concentrations are highly variable and dominated by natural variations in soils"
    - This statement applies to gamma radiation but is not supported by water or food data, as discussed above
- "Eating land and aquatic based foods are the largest contributors to ingestion radiation dose"
    - The evidence clearly supports this finding
- "The food dose contribution varies according to the location and diet, with diet assumptions of each community being the dominate (sic) variable"
    - Most of the variation is due to differences in food consumption patterns among communities (see my discussion above)
- "Drinking water and dust are minor dose contributors"
    - Dust data are very limited but support this finding
    - Water data are subject to numerous issues, which are presented earlier. The largest issue is the lack of data from the MMM River during mine wastewater discharges and the weak evidence supporting a 90% dilution factor for wastewater released to the river. Another important issue is the complete lack of any discussion of the role of river flow in determining both background and mine-related radionuclide concentrations. Flow often is the primary driver of water quality.

The overall level of conservatism in dose estimates is not presented nor discussed in the report. In other words, what is the level of confidence that doses have not been underestimated? This is important both with respect to the ICRP intervention level of 20 mSv/y and the mine-related incremental contribution to dose limit of 1 mSv/y because both represent "triggers" for application of the ALARA principle.

Discussion

Many references to the importance of "large natural variability" are made in the report. This theme is used as the primary reason for the difficulty in determining mine-related incremental contributions to radionuclide levels and doses as well as demonstrating regulatory compliance (p.45). I point out several times in earlier comments that only gamma radiation levels show "large variability". Measurements of radionuclide concentrations in dust, water and food are not nearly as variable as gamma radiation. The variability is commensurate with the combination of measurement error associated with levels close to detection limits, and sampling error associated with how well (or not) the sample design accounts for important confounding variables such as water flow, sediment and soil texture, size, fish size and age, and local vs long-range wet and dry deposition.

The radiation doses for people in the Mandena study area reflect the specific natural and human environment. JBS&G point out that many mineral sands areas in the world do not have subsistence villages eating quantities of aquatic food (fish, shellfish) and most, in fact, are in arid environments (p.45). They go on to list several important factors that contributed to the results (p 45-46). This list provides useful context for the results and should be considered if/when follow-up studies and monitoring programs are designed; e.g. a study of mine wastewater discharge dilution and downstream transport of radionuclides to depositional sediment areas.

JBS&G make particular note of the importance of aquatic food ingestion in determining total dose and describe an initial estimate of “many tens of samples” which would be required to achieve what is called a “range separation” between on-mine and off-mine fish concentrations. The high sampling effort is attributed to “high natural variability” as well as the “ineffectiveness of attempting to establish ‘background’ or ‘control’ sites” (p. 47). These types of challenges are common. This is why Steps 6 and 7 of the DQO process focus on iteration in determining tolerable decision error for decision-making or acceptable error ranges for estimates. The initial estimate of the required number of samples is almost always impractical/impossible. This is when explicit examination of trade-offs between sample sizes and certainty, as well as the ‘consequences of being wrong’ come into play. Involvement of regulators in these deliberations is important.

The social dilemma associated with acquiring sufficient fish samples in an area where this might affect a family’s meal is identified on page 46. This dilemma can only be addressed if there are relationships based on trust which can then lead to effective discussion of solutions. For example, payment for samples taken from subsistence fisheries could be negotiated.

After considering all potential pathways leading from the mine, JBS&G targeted the water and sediment pathway for further investigation, both “surface water within the mine perimeter (in release and decantation ponds) and sediment in the river and lake system out of the mine site” (p. 47). I suggest that this study should include water as well as sediment in the river system. The design should include definition of the mixing zone under high and low flow conditions as well as identification of true depositional areas for sediment sampling. Mixing zone studies usually involve the use of tracers, which can be instrumental in increasing confidence in the size and boundaries of the mixing zone.

Conclusion

The Executive Summary concludes that “the likely impact to the public from inhalation and ingestion resulting from operational activities, were (sic) expected to be small or insignificant from most pathways and would be within regulatory limits”. The Conclusion section of the report states “The Study has demonstrated that there is no need for heightened health concerns around local radiation levels, and that the mine has not significantly contributed to increasing these naturally occurring levels over the period of its operation” (p. 49).

Close examination of these statements is required. What is meant by “likely”, “small” or “insignificant”? How sure are we that there is no need for heightened health concerns? How strongly do the data support the assertion that the mine has not significantly contributed to increasing radiation levels. A formal, statistical analysis would be required to make such definitive statements.

If statistical analysis is not possible due to data limitations, minimizing the likelihood that doses are underestimated can be achieved by a consistent and defined level of conservatism, with deliberate choice of upper or maximum values for parameters which are important drivers of total dose. The conservatism built into the dose calculations is not described in one place in the report. A narrative describing the level of confidence in the dose estimates which was achieved by conservative approaches and assumptions was not provided.

I interpret the wording of the report's overall conclusions to mean that JBS&G expects that their calculation of dose using mean concentrations measured in dust, water, and food items, and their interpretation of diet survey results produced dose estimates that, *in their professional judgment,* did not exceed 1 mSv/yr in excess of natural background dose.

The key remaining question is "what is the chance that doses could be higher than those calculated in the report?". This pertains to the protection of the general population but also more sensitive or more highly-exposed individuals, as discussed above for the 15 year-old critical group. There needs to be an evaluation of the possibility that total doses from background plus mine-related exposures can exceed the ICRP intervention level of 20 mSv/year in certain critical sub-groups.

In the face of the inability to fully evaluate the level of confidence in results, the importance of ALARA becomes preeminent. ALARA should start with managing mine-related sources. ALARA provides additional protection when it's very difficult to implement a monitoring study design which is rigorous enough to produce the desired level of confidence.

JBS&G state that "the ongoing management of radiation at the Mandena mine must remain a focus of Rio Tinto, QMM and Government Regulators." This is particularly true for the exposure pathways which are the highest contributors to total dose. I note that radiation protection applies to individuals as well as populations. Every individual matters and deserves the same degree of protection from mine-related exposures. Implementing ALARA principles in a consistent and well-monitored manner would help ensure that protection. The aim should be to ensure that radiation doses in even the most sensitive individual and/or an individual whose day-to-day activities would tend to maximize exposure would be less than doses deemed by the ICRP to justify intervention. For example, it is unclear that the calculated doses would encompass situations such as wood cutters entering the mine site.

The questions raised above are meant to provide a focus on additional ALARA-based actions which would further reduce mine-related exposures. The aim is to increase confidence that all doses, including doses received by sensitive or more highly-exposed individuals, are well below the ICRP intervention levels for high natural background areas.

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Attachment 1

Comparison of Data Quality Objectives Process with What Was Done in the Study

The following comparison is based upon the US EPA Data Quality Objectives Guidance.

US EPA. 2006. Guidance on Systematic Planning Using the Data Quality Objectives Process. EPA QA/G4. EPA/240/B-06. United States Environmental Protection Agency, Washington, DC. https://www.epa.gov/quality/guidance-systematic-planning-using-data-quality-objectives-process-epa-qag-4

The comparison follows the seven-step DQO process and notes when the JBS&G study followed the guidance and when it did not.

One of the first steps in the DQO process is to identify the *intended use* of the data. The most common intended use is **decision making**. "In this context, decision making is defined as making a choice between two alternative conditions. At the time a decision maker chooses a course of action, the resulting consequences are usually unknown (to a greater or lesser degree) due to the uncertainty of future events. Therefore, a good decision maker should evaluate the likelihood of various future events and assess how they might influence the consequences or "payoffs" of each alternative. This is where statistical methods help a decision maker structure the decision problem. The DQO Process has been designed to support a statistical hypothesis testing approach to decision making." (US EPA 2006). **Estimation** is another common intended use. "The goal of a study is to evaluate the magnitude of some environmental parameter or characteristic, such as the concentration of a toxic substance in water, or the average rate of change in long-term atmospheric temperature. The resulting estimate may be used in further research, input to a model, or perhaps eventually to support decision making. *However, the defining characteristic of an estimation problem versus a decision-making problem is that the intended use of the estimate is not directly associated with a well-defined decision.* "(US EPA 2006, emphasis added).

The intended use of the data is not declared in the JBS&G report. The study appears to primarily be focused on estimation. However, the results are obviously directly relevant to corporate and regulatory decision-making. The issue is that DQOs for data collected to provide decision-makers with a statistical basis for discriminating between alternatives (e.g., the need to treat water or not, or evaluation of alternative measures to further reduce dust generation) can be quite different from DQOs for data collected for estimation.

Step 1. State the Problem

- *Done*. "….an attempt to quantify the surrounding community member radiation doses from naturally occurring radioactive materials and any contribution from the decade plus of mining activities" (p. 1).
- Develop a conceptual model. Done. Section 6.2 of the report. (pp.20-24)
- Identify the intended use of the study data – Decision-making or Estimation. Not clear.

Step 2: Identify the Goal of the Study

- *Done*, although the following quotes are not presented as goals. "To determine the total effective radiation dose that local community members may receive" (p. 1). "To estimate the total effective dose, the cumulative dose from each source and each pathway will need to be considered in the assessment" (p. 21). These statements could be taken as the overall goal or purpose of the study

- Identify principal study questions.
    - *No explicit principal study questions* for the study components except for surface and groundwater "measure the level of radionuclides present within the water system to determine if the process of mining has resulted in enhanced concentrations of radionuclides compared to those present in water considered representative of background influenced only by natural processes" (pdf p. 163, Appendix A4)

Stated objectives or study questions:

- Gamma radiation surveys – no objectives or questions presented but the scope was described as "limited to targeted surveys of potential direct radiation pathways associated with transport and storage of REC and comparative surveys using survey meters appropriate for environmental radiation surveys (low limit of detection) of residual concentrations within the remediated zones for comparison of surveys undertaken by QMM" Appendix A-1
- Radon and Thoron – no objectives or questions presented. The locations were selected at the same locations as the seven passive dust stations with a sample pattern "selected to capture the highest potential for exposures downwind of the mining operations together with background control locations that would not be impact by mine operations" (Appendix A-2
- Dust - no objectives or questions presented. Implied by design of dust sampling locations which were along a transect from upwind/upgradient of mining operations through to downwind/downgradient. Appendix A-3
- Surface and groundwater: "measure the level of radionuclides present within the water system to determine if the process of mining has resulted in enhanced concentrations of radionuclides compared to those present in water considered representative of background influenced only by natural processes" Appendix A-4. I assume that "enhanced" implies a statistically significant difference between upstream and downstream results but this is not explicitly stated.
- Soil and Sediment: no objectives or questions presented. Soil sampling appears to be an add-on to supplement what is described as "extensive soil sampling results undertaken by QMM across the Mandena mine lease" and the baseline data collected by SENES. Sediment samples "at targeted locations within the mine process water settlement pond network" and offsite "at locations along the receiving water environment within the MMM river at locations collocated with historical water quality sampling locations starting up gradient at the MMM village following down to the discharge point into the Ambavarano Lake." Background sample points at "Mangaiky and along the Enandrano River, along the Meander River, at locations within the Meader and Ambavarano lakes and in the village of Evathraha".
- Foodstuff – no objectives or questions presented. Objectives can be inferred to include collection of data on seasonal dietary habits, and measurements of radionuclides in plants, grain, fruits and vegetables as well as shrimp, prawns and fish.

- Consider alternative outcomes or actions and develop decision statements or state what needs to be estimated and key assumptions
    - *The goal statements on pages 1 and 21 quoted above indicate that the intended use of the data was primarily estimation.*
    - *Key assumptions can sometimes be inferred from the study design but are not identified explicitly*

Step 3: Identify Information Inputs

- Types and sources of information needed to produce estimates
- *Some but not all information inputs were identified*
    - Inferred from the description of sample sites and analytical methods
    - Supporting information was sometimes identified, presented and discussed; e.g. particle sizes and deposition rates of dust; sediment texture
    - For some study components, notably water, neither the report nor the Appendix mentioned or discussed supporting information such as field parameters (pH, temperature, dissolved oxygen, electrical conductivity, redox potential), although field records indicated that these data were collected
    - The basis for decisions to collect new data (e.g. a few new soil samples) or to add sampling stations was not always explained
    - the limitations of baseline data (e.g. high detection limits) and applicability to comparison with the study data were not discussed in any detail
    - information on specific sampling and analysis methods was presented in Appendices, although not always to the same level of detail for each study component

Step 4:Define the Boundaries of the Study

- Define the target population of interest and its relevant spatial boundaries
    - *This varied with study component, which is understandable*
    - Figure 12 and the accompanying explanatory caption was helpful (p. 21)
    - Spatial boundaries sometimes shifted as the study progressed (e.g., water sampling rounds), which also is understandable and consistent with taking an iterative approach - but explanations and discussion of the effect of these shifts on data interpretation would have been helpful
- Specify temporal boundaries and practical constraints
    - *The timing of sampling was unclear so it was difficult to determine whether the data could be used to evaluate seasonal or annual variability*
    - *Practical constraints were identified and actions taken to address them were described in the Appendices*
    - *The time frame for which the estimates (or, if applicable, decisions) are relevant was not explicitly stated.*
- *The scale of inference for estimation or decision-making was not explicitly stated nor discussed for the individual study components.*

    - The scale of inference for the gamma radiation study of trucks transporting rare earth concentrate, ilmenite and zirsill is obviously much smaller than the scale of inference for water.
    - The scale of inference for food data is a particular challenge due to the differences in food survey results among communities.
    - The scale of inference will vary according to whether the data are being used in dose estimation or for determination of mine-related incremental contribution to dose. For example, should results from water sampling stations potentially representing a dilution zone be considered separately from results produced by stations further downstream?
    - Protection of the entire population in the study area implies a different scale of inference than for specific sub-populations such as woodcutter or specific age groups such as 15 year-olds
    - The unit of area, time period, and parameters (average, minimum/maximum, median) may vary depending on the scale of inference

Step 5: Develop the Analytic Approach

- Specify appropriate parameters for making decisions or estimates
    - *Averages were the most commonly used parameter, with occasional reference to medians and/or minimums and maximums.*
    - There were no depictions of data distributions; therefore, it is unknown whether distributions are normal, lognormal, bimodal etc. and percentiles were not determined nor presented
    - Minima and maxima were depicted in figures
    - It was unclear whether ± amounts shown in results tables were always from laboratory duplicates, or whether field duplicates were sometimes represented
- Choose an action level for decision problems
    - *The ICRP "intervention level" of 20 mSv/y and the regulatory limit of 1 mSv/y for incremental mine-related contributions to total dose were explicitly identified in the report, but it is unclear whether these are strictly to provide context for dose estimates or whether they are also intended to serve as action levels.*
    - The EPA guidance suggests that an action level may be relevant to estimation problems if scientific studies or regulations specify a threshold value of exposure. The 1 mSv/y limit for incremental contribution to dose would qualify. In this case, a key parameter to be estimated would be the proportion of a population that is exposed to conditions above that threshold value. *Average dose indicates the central tendency and is appropriate for cancer risks after long-term chronic exposure (US EPA 2006).*
    - Once the action level and parameter are established, a theoretical decision rule is developed, usually in the form of "if…then…else" statements
    - *For estimation problems, a statement specifying the estimator is developed. There were no such statements in the report.*
        - For example, "the study will estimate the gamma radiation exposure to a member of the public due to being in the vicinity of a truck transporting rare earth concentrate at a crossroads; at varying distances from the truck".

Step 6: Specify Performance or Acceptance Criteria

- *This step was not performed.*
- For decision problems, specify the decision rule as a statistical hypothesis test, examine consequences of making incorrect decisions from the test, and place acceptable limits on the likelihood of making decision errors "tolerable decision error"
- For estimation problems, specify acceptable limits on estimation uncertainty
    - Sampling error and measurement error need to be managed to achieve tolerable decision error
    - Sampling error is usually much larger than measurement error and thus needs more resources to control
    - The missing baseline for water and food means that estimating incremental contributions from QMM is uncertain.
- The report did not include decision rules and did not specify acceptable limits on estimation uncertainty
    - Thus, there are no statements made regarding the level of confidence in the estimated total doses as well as estimated mine-related incremental doses.
    - In the absence of decision rules or statements of required confidence in estimates, qualitative narratives describing sources of uncertainty would have been helpful. Narrative statements regarding uncertainty were rare and did not accompany the overarching conclusions made in the report
    - "These dose levels are as a result of naturally occurring radiation levels, with no evidence of significant contributions from mining activities being found.".(page 2) The doses referred to are those from ingestion of food and water plus inhalation of dust. The statement does not acknowledge that there was only one baseline fish and one baseline crab sample and no other food data. Baseline water data were subject to high limits of detection for most radionuclides (typically above 1 Bq/L). The use of the phrase "significant contributions" implies statistical analysis. There were no data to support such analyses. The extremely limited baseline for water and food meant that quantitative decision rules or acceptable error limits could not be derived
        - Thus, a defensible qualitative narrative for this overarching statement is required. The narrative should clearly acknowledge the uncertainties associated with this statement as well as the consequences of being in error.
        - The narrative could include explicit consideration of specific critical groups such as woodcutters who are exposed to gamma radiation on site plus water, food and dust and 15 year-olds who live near or frequent black sands areas with higher gamma levels plus water, food and dust exposures.
    - Concentrations in the MMM River resulting from releases of mine water were inferred, not measured, because sampling took place during periods when releases were not taking place. There are no data to either support or reject these inferences from periods corresponding with releases.
    - in support of the assertion that total doses are a result of naturally occurring radiation levels and that there is "no evidence" of

- Statements of confidence in the establishment of baseline statistics such as means, medians and percentiles must be based upon an understanding of fundamentals such as the distribution of baseline data; i.e., whether the distribution is normal (bell-shaped) or not. If the distribution of data is not normal, then a critical assumption underlying any parametric statistical analysis is violated and alternative statistical analysis methods must be used. The report contained no statements regarding the distribution of baseline data. Therefore, there is no way of judging the validity and rigour of statements made regarding contributions of mining to total dose or the degree to which the incremental mine-related dose might approach or exceed 1 mSv/yr.
- There is also no way of quantifying the confidence that doses received by specific critical groups (e.g., 15 year-olds) would be unlikely to exceed the ICRP intervention level of 20 mSv/year. In order to be able to make these evaluations, explicit tolerable decision error statements are required, as described in EPA (2006). For example, "we are 95% confident that 90% of doses to the critical group will fall below the ICRP intervention level".

Step 7: Develop the Detailed Plan for Obtaining Data

- *The study design was based on the judgement of the study team, rather than statistical inference.* Statistical inference requires a probability-based sampling design, as this type of design will allow you to properly characterize uncertainty. "Because the DQO Process is centered on properly dealing with uncertainty in your data, such designs are highly recommended as part of this process" (EPA 2006).
- Examples of common probability-based sampling approaches include simple random sampling, stratified sampling, and systematic and grid sampling. Probability-based sampling allows you to draw quantitative conclusions about the target population, while also properly expressing uncertainty in these conclusions through calculating confidence intervals, controlling for decision error probabilities, etc.
- "Judgmental sampling involves the selection of sampling units on the basis of expert knowledge or professional judgment. Emphasizing historical and physical knowledge of the underlying site condition and sampling units over the need to implement potentially complex statistical sampling theory make judgmental sampling an appealing option for some applications. However, judgmental sampling designs will not allow you to characterize uncertainty properly. As a result, the outcome of statistical analysis on data collected through judgmental sampling cannot be used to make any type of scientifically-defensible probabilistic statements about the target population. Conclusions are made solely on the basis of scientific judgment, and therefore, depend entirely on the validity and accuracy of this judgment." (US EPA

There is reference to "project data objectives", but these objectives are not always presented. In the DQO process, data objectives normally include the number of samples required to achieve a specified degree of confidence in the results. For example, it might be decided that the desired degree of confidence in being able to distinguish the incremental contribution of the mine operations to total dose is being able to correctly distinguish the mine contribution 70% of the time. In order to achieve 70%, the number of samples (replicates) per location is 4 and the number of stations is 18. In situations where there is high natural variability, a higher number of samples per location and more locations will be needed to be sufficiently sure that there are, or are not differences between upwind and downwind of the site, or between upstream and downstream samples from the river.

Summary

DQO guidance was not followed consistently nor comprehensively

As a result, uncertainty cannot be characterized.

Thus, the likelihood that the following statement is correct cannot be determined "these doses are as a result of naturally occurring radiation levels, with no evidence of significant contributions from mining activities being found". It can only be evaluated by examining the available data at face value, combined with the professional judgment and experience of the reviewer.

The degree of concern associated with the inability to characterize uncertainty (the likelihood of being wrong) depends on the consequences of being wrong. Consequences will be highest in groups which are the most sensitive and/or the most exposed. How sure are we that the risk to the most exposed and the most sensitive groups (which may not be the same groups) is well enough understood that the use of the ICRP intervention level of 20 mSv/year and the regulatory limit of 1 mSv/year above the naturally occurring dose is sufficiently protective?

Exposure and dose: The baseline data and the data collected by JBS&G show that the population living in the study area is exposed to high natural background radiation. The data also show a high level of variation in background radiation, often within very small areas. The JBS&G dose estimates indicate that 15 year-olds as the most exposed. Who within this group might have exposures which are above the average? Why? Where do they live relative to proximity to the mine and/or proximity to the most elevated natural background (e.g. black sands)? Are there other age groups where some individuals have higher exposures (e.g. woodcutters)?

Attachment 2

Comments on the Gamma Radiation Component of the Study

Appendix A1 pdf page 59-100

Focussed on direct pathway from transport and storage of rare earth concentrate as well as residual concentrations within remediated zones for comparison of surveys done by QMM.

Also “ad hoc” survey measurements during 2019 and 2022 sampling events at 5 village locations – Andrakaraka, Emanaka, Ampasy, Mandromondromotra and Evatraha.

<u>Rehabilitated Zone Gamma</u>

(1) Date: May 12, 2019. Transect across a recently rehabilitated rehabilitation zone adjacent to the buffer zone on shore of Lake Ambavarano. Seven measurement points leading away from the buffer zone across the rehabilitated zone towards active mining area. Also, a group of seven measurement points running parallel to the shore within the buffer zone – apparently although the Figure 8 in the report and Figure 3 in Appendix 1 does not provide the boundary of the buffer zone. It appears that the area is not within the rehabilitation zone based solely on colour of soils. Unclear which gamma survey metre was used for this transect study. JBS&G state that they used two meters – Atomtex AT1125 with range of 0.03 to 300 uSv/h and Atomtex AT1121 with range of 0.05 to 10 Sv/h(page 61 of 2111). QMM used a ThermoScientific Electra and a ThermoScientific RadEye G-10 for truck study and the Electra for their rehabilitation zone 40mx40m grid sampling.

Data were interpreted as confirming conceptual model prediction of reduced gamma dose rate within remediated areas due to removal of mineral sands during mining.

(2) Dates: 40x40m grid surveys. June 2016 and Dec 2018 – QMM. Dec 2019 – JBS&G. Comparison with QMM survey results affected by JBS&G not having access to the same gamma survey meter (the ThermoScientific Electra) as used by QMM and the only one available (ThermosScientific RadEye) was not adequate for readings below 0.5 uSv/h. NOTE: most of the readings were below 0.5 uSv/h. No mention of the INSTN data in Figure 9 – one measurement point was 19 uSv/h. But only two INSTN points appear to be shown in Figure 9.

<u>Compare with Swanson 2019.</u>

Quotes from Swanson 2019 Used QMM data.

The 2016 data were from an area before mining occurred. The 2018 data were post-mining. The coordinates of the sampling locations were checked on a location by location basis, and if they were identical, they were included in the analysis. If there was no match then the data were excluded. At each specific location the pre and post mining gamma rates were examined and subtracted from each other. The difference represents the operational contribution to the gamma dose rate at that specific location. Locations which were still under active use (such as two locations in the plant area) and locations which were still undisturbed by mining (under original vegetation) were similarly discarded. This process yielded 166 sampling locations with pre and post mining gamma dose rates.

The post-mining median gamma dose rate was 0.20 µSv/h which is a decline of 0.11 µSv/h from the pre-mining median dose rate of 0.31 µSv/h (Table 2). The gamma data were highly variable across the site, as shown by the high standard deviations in Table 2. Much more sampling is required to obtain a more confident indication of the site wide gamma dose rate post-mining and whether there may be specific areas where post-mine exposure has increased.

For the sampling points analysed, the annual dose for permanent habitation would decrease from a pre-mining gamma dose of 2.7mSv/y to a post mining gamma dose of 1.8mSv/y (Table 2). Although still on the upper range of natural values globally, it is well within the natural variation in the region around QMM because of the significant natural mineralisation in the region. The analysis of the pre-mining and post-mining measurements confirmed what would be expected from theory. Due to the preferential disposal of heavier sands at depth, the gamma dose rate post mining may be reduced from that which existed in the natural pre-mining background. However, this is only true if a large area is considered because due to the nature of the mining and subsequent reposition of reject sands, there will be a high variability on a location by location basis.

Appendix A-1 is unclear with respect to gamma measurements pre and post-mining. Figure 9 apparently shows QMM (green dots) and INSTN (yellow red and purple dots) data for the same area as where JBS&G measured gamma dose rates in a transect leading from the buffer zone across a remediated area (blue and white dots). Assuming that I understand Figure 9 correctly, I don't understand how the pre-mined remediation area had an average dose rate of 0.13 uSv/y (assuming that this statement on page 68/2111 refers to the remediated area after remediation and is based on only the JBS&G data). If just the JBS&G data are used the mean is 0.19 uSv/h. If the QMM data are included, the mean is 0.27 uSv/h. If JBS&G, QMM and INSTN data are used the mean is 0.76 uSv/h. Figure 9 shows QMM from 2016 only (premining), 2018 only (postmining), or both? And some of the data points appear erroneous – e.g. a QMM data point of 0.180.26 and an INSTN data point of 0.388.13. There is also an INSTN reading of 19 which is higher than any of the baseline gamma measurements reported by SENES (see Table 2 of Appendix A-1) and higher than the highest dose rate within the controlled area at the Port of Ehoala as reported by JBS&G (see Figures 12 and 13 of Appendix A-1). INSTN reported a maximum gamma dose rate of 72 uSv/h adjacent to monazite ore stockpiles. But one would not expect a reading of 19 in a remediated zone post-mining. So, this is probably a transcription error.

Far fewer JBS&G measurement points than the QMM measurement points and using a different meter which produced measurements which were not reliable below 0.5 uSv/h. This confounds comparisons between JBS&G and QMM data. Plus, the INSTN data shown in Appendix A-1 Figure 9are confined to only two measurement points. I assume that Figure 9 is just a sample of the QMM and INSTN data. Perhaps because that sample is what corresponds to JBS&G data which are much more limited.

Not much new evidence for comparison of pre and post mining gamma dose rates. The new data are insufficient to support the overall conclusion statements regarding remediated area dose rates. The pre and post-mining study design was limited to one area near the buffer zone adjacent to Lake Ambavarano. Only one true transect was established. Replicate gamma readings were not reported – a concern given how variable gamma readings can be within a short distance. There was no discussion of the rehabilitation methods, including how recently the area had been rehabilitated. **The transect data (as depicted in Figure 8) is in**

accordance with analysis of Swanson (2019). But no further confidence can be obtained from the data presented in Figure 9 where QMM, INSTN and JBS&G data are presented. See page 35 of 2111 for general conclusions.

Truck Study

Located at a crossroads where trucks going to the Port of Ehoala must stop as well as set distances from trucks loaded with REC, ilmenite and zirsill within a low background area

Measured within the mine, in rehabilitated and unmined areas, in and around the Port during maximu REE concentrations storage capacity, in areas and villages around the mine while sampling for other media or during reconnaissance, and within village of Evatraha.

Also deployed Luxel+ dosimeters over a period of 5-6 months for the first deployment and just over 2 months for the second deployment.

Locations: Crossroads 1 and 2 along mine haulage Road as well as Office.

Deployment 1 – 3 dosimeters at the Crossroad 1 and 2 at Crossroad 2 – on either side of the crossroad so could compare doses from loaded and empty truck sides. Theft at Crossroad 2 .

Deployment 2 – Crossroad 1 only. Two monitors on each side of the road.

Results

Port of Ehoala – 2019. Days preceding a ship loading while port was at max REC concentrate storage capacity. Areas accessible to public around port perimeter. Highest dose rate within fence was 11 uSv/h. Just outside the fence highest measured 0.66 uSv/h. Average dose outside fence was 0.34 uSv/h. Max dose in areas accessible to public was on natural ground on path leading to the beach with no evidence of windblows or imported material. This dose is not given but is described as "comparable to the data collected in 2000 by SENES where natural background dose rates were comprised between 0.6 and 1.2 uSv/h" (page 69 of 2111).

Ad hoc gamma readings in villages - 2019

> Done while installing dust and radon/thoron stations and sampling for soil or food. 27 dose rate measurements. Range from0.04 to 0.37 uSv/h.
>
> Evatraha – October 2022 –
>
> 0.42 to 2.45 uSv/h and 0.53 to 1.33 uSv/h on black sand on southern shore of the lake. Range of 0.3 to 2.2 uSv/h in a single rice paddy.

Overall statement re Ad hoc measurements-

> Dose rates measured by JBS&G fall in the SENES baseline range for the Mandena area and dose rates in Mandena area had the lowest natural background dose rates compared to Fort Dauphin, Port of Ehoala and Evatraha (east of the weir).

All measurements taken by JBS&G within the range of regional measurements done by INSTN in 2014 where dose rates were from 0.06 to 0.70 uSv/h.

Overall statement – wide range of gamma dose rates reflects widespread presence of heavy minerals across the region with localised variations of NORM distribution.

Table 2 has a good overall summary of SENES data – page 71 of 2111. Thousands of gamma readings so could have produced a data distribution which would have been very useful in terms of study design focussed on data performance criteria for doses to critical groups of people and for determination of mine-related incremental doses. Could have added the new data to see where it fits on the distribution.

Truck Study

Used a location 160 m from a dust monitoring site which recorded a low ambient dose rate. The dose was 0.1 uSv/y on the side of the road (ThermoScientific Electra).

REC - Highest dose at surface of truck (51 uSv/h) which declined rapidly with distance – see Table 3 on page 72 of 2111. Background rates at 10 m.

See Table 4 page 74 of 2111. Annual incremental dose 1 m away is 0.062 mSv and 0.003 at 5 m.

Ilmenite and Zirsill -

Annual incremental dose 1 m away from truck 0.009 mSv (ilmenite) and 0.011 mSv (zirsill)

Crossroad Surveys

Deployment 1 – Nov-April 2021

Data from first deployment "inconclusive and unreliable"

Deployment 2- Aug-October 2021 (cooler months)

Overlapping ranges of doses from northern and southern side of crossroads (loaded vs empty trucks) so concluded that the data do not show a "conclusive impact" from transit of the trucks on the ambient dose at the crossroad". (page 78 or 2111).

Very limited data – with only one valid measurement campaign. Need to hear whether QMM intends to repeat the measurements, including at least 2 replicates per sample location since the variability for the duplicates on the northern side and southern side are right at the 15% tolerance reported by the manufacturer of the dosimeter devices.

Need to see the variability of background doses. Average dose rates are presented with no standard deviations.

What was the assumed total number of hours of exposure per year for each distance from the truck? Was it the same number of hours for each distance?

Swanson 2019 assumed 200 minutes 1 m away yielding a dose of 0.27 mSv/yr.

The JBS&G dosimeter measurements yielded a dose of 0.062 mSv/y for a person 1 m away. This appears to reflect an assumed total exposure time of about 70 minutes over one year.

Attachment 3

Notes and Comments on the Dust Component of the Study

Appendix A3 pdf p. 121-161

7 passive dust monitoring stations

- 2 upwind (Mandromondromotra and station DS04 west northwest and upwind of the mine
- 4 downwind (Mandena Mine Gate, Maroamalona, Ampasy, Toby)
- 1 cross/downwind (Andrakaraka)

Initially set up in Nov and Dec 2019. Heavy rain in Jan 2020 le to overflow of the gauges. So, all stations reset in Feb 2020. First deployment Feb-Nov 2020 covered the cold and dry month. Second deployment too place in the wet season (Dec 2020 to April 2021).

DS01 (Mandena mine gate) damaged due a reversing vehicle colliding with it on April 14 2021. The contents of the disturbed collection vessel were preserved and prepared separately for analysis.

Gravimetric analysis for deposition rate

Average deposition rates over the two deployments were compared to dust concentrations in the air from QMM's air quality monitor. Deposition rates were generally consistent with dust concentrations in air measured from Jan 2020 to Dec 2021.

Upwind and downwind areas had comparable deposition rates. The station closest to the mine at Maroamalona had the lowest deposition rate during the second deployment but not the first. Toby – eastern outskirts of Fort Dauphin, had highest dust deposition rates for all particle sizes.

Interpretation of dust deposition vs dust concentration in air results is limited to a qualitative narrative. The dust deposition results are described as "generally consistent with the dust concentrations in air" (page 125/2111). There is no statistical analysis (e.g. regression of concentration against deposition). The number of individual measurements per station used to calculate average dust concentrations per particle size category is not reported. The "average" dust deposition rates in Table 3 were presumably calculated from two measurements – one of total dust collected from deployment 1 and one of total dust collected from deployment 2. However, the averages could also have been calculated from analysis of dust from individual retrievals of the contents of gauges (which apparently could be as frequent as weekly due to high rainfall). In any case, standard deviations are not presented in Tables 2 (page 125/2111) and 3 (page 126/2111. Furthermore, as far as I can determine, duplicate gauges were not set up at any of the stations. 1

Measured PM1, PM10 and PM2.5

Measured U238, Th230, Ra226, Po210 Th232, Th228 in insoluble fraction only by alpha spec and ICPMS only due to limited mass of samples

Interpretation of radionuclide results is also limited to a qualitative narrative. The means and standard deviations in Table 4 (page 127-128) and Table 5 (page 128-129/2111) are based on 2 samples per station (1 per deployment presumably consisting of a composite of retrieved samples from each gauge over the deployment period). Presentation of means and standard deviations derived from only 2 data points per station is not warranted and could be misleading. It would be preferable to present the results for each of the 2 samples per station.

Comments on the summary description of results

“Breathing in dust across the region has a very small radiation dose of 0.07 mSv/year. (page 37/2111).

> This statement is based on 2 samples per station. It is good to finally have data on radionuclide concentrations in dust. And the results indicate that dust is probably not a major contributor to total dose. But the level of confidence in this statement would increase had there been an ability to compare within-station and between-station results via the deployment of at least 3 replicate gauges located at a minimum of one upwind and one downwind station.

“Maximum possible dust contribution for the mine site is less than the total dose of 0.07 mSv and estimated to be 0.02 mSv using a downwind/upwind subtraction method.”.

> The data are not sufficient to claim that a maximum possible dust contribution for the mine site is known. Two samples each from 2 upwind and 4 downwind sites is a small dataset – albeit a welcome start.

Swanson 2019 assumed 200 minutes 1 m away yielding a dose of 0.27 mSv/yr.

The JBS&G dosimeter measurements yielded a dose of 0.062 mSv/y for a person 1 m away. This appears to reflect an assumed total exposure time of about 70 minutes over one year.

Attachment 4

Notes and Comments on the Water Component of the Study

Appendix A4 pdf page 163-312

15 Surface Water Sampling Sites. 4 Rounds of sampling. <u>Duplicate samples for SW07 only</u>.

Upstream of discharge: SW02, 03, 13, 14,

Adjacent to discharge point: SW07, 08, 09, 15

Downstream of discharge in order from closer to mine to entrance to Lake Ambavarano: SW 06, 05, 04 (entrance of MMM R to Lake A)

Small pond Ambondrombe between mine lease and MMM river – SW01

Lake A: SW10 – close to weir and 12 – W side adjacent to Emanaka

Meander River adjacent to Andrakaraka: SW11

8 Groundwater sampling sites

Village springs

Village water wells

Mine piezometer wells

The sampling stations sampled in each round varied for both surface water and groundwater. None of the sampling rounds included all sample sites.

The analyses varied among rounds.

Round 5 added – mine lease only – starting at the mineral separation plant and along the internal settlement pond and wetland system. This was done to generate data to use to predict concentrations in the MMM river after discharge of water from the mine site since the other sampling times apparently did not coincide with mine water discharges.

8 GW. Sample rounds varied from only 1 round (GW8 in Andrakaraka) to 4 rounds (GW4 Mine site piezometer). 2 rounds for GW02, GW06. Three rounds for GW01, GW03, GW05, and GW07. 4 community drinking water – Emanaka village hand pump well; Village spring within MMM village; hand pump GW well close to MMM school, and Andrakaraka. 4 mine piezometers on the mine site. Two of these (GW05 and GW06) were within the mineralized zone yet to be mined, GW07 was within the rehabilitation area and one was not described (GW04)

GW04 on the mine site was the only location sampled for all 4 rounds. The other stations were sampled on 2 or 3 rounds except for GW08 (Andrakaraka) which was only sampled in round 2.

<u>Surface Water analytes – Round 1. Dates??? – not reported in the text of Appendix A-4.</u>

U238, Th230, Ra226, Th232, Th228 for 1,2,3,4,5,6,7,8,10,13,14, WMC703A

Gamma spec for Pb210 and Ra228 for subset of 4 SW samples – 9, 11, 12, 15 (all less than LOD). Plus U238, U234, Th230, Ra226, Po210, U235, Pa231, Ac227, Th232, Th228, K40.

No overlap between SW samples analysed by alpha and ICPMS only and the samples analysed by gamma spec so can't compare results for U238, Th230, Ra226, Th232, Th228 between ICPMS (ICPMS) and alpha spec (Th230, Th232, Th228, Ra226)

Reported results for each round. Unclear what the error bars represent. Were there duplicates or were samples taken at different times and results from all sample dates averaged?? Only specific mention of duplicate samples is for SW07. Assume the error bars are from laboratory QC checks only?

Sampling dates for rounds are not reported in the text of Appendix A-4. Figuring that out would require going through all of the individual field collection record sheets.

Tables 3 Surface Water pdf p. 168

Most results are less than detection, except for Ra226 and one result for Th228. Ra226 concentrations very low.

Table 4 Gamma Spec Subset Surface Water pdf p. 169

U238, Ra226, U235, detectable. All other radionuclides less than detection limit.

Table 5. pdf p. 170. Groundwater: Concentrations in village groundwater wells/springs less than detection limits except for Ra226. Mine piezometer concentrations were detectable (except for U238) but low. All below WHO guidelines.

Table 6 Groundwater and Surface Water pdf p. 171

Ra226 and Po210 detectable in groundwater and surface water

All other radionuclides less than detection.

Table 7 Groundwater and Surface Water on Mine Lease or at Discharge Point or adjacent to discharge in the MMM River pdf p 172

Ra226 always detectable but at low concentrations – lower in surface water than in groundwater

U 238, Th230/ and Th228 detectable in groundwater but not surface water

Table 8 1 upstream and 4 Downstream surface water pdf p 172

Ra226 detectable downstream but not upstream

All other radionuclides less than detection

Table 9 Gamma Spec subset pdf p 173

U238, U234, Ra226, Po210, U235 detectable in the 1 groundwater sample

U238, U234, Ra226, Po210 U235 detectable in most of surface water samples (4 samples)

Table 10 Upstream 1 Groundwater 3 Surface water pdf p 174

Ra226 detectable in groundwater and 2 of 3 surface water – levels very low

Po210 detectable in groundwater and the 1 surface water which was analysed

Th232 and Th228 detectable in 1 surface water sample

Table 11 Mine Discharge or Mine Lease plus 2 surface water adjacent to discharge pdf p 175

Ra226 detectable in all samples – higher levels on mine lease than elsewhere

Th230, Th232, Th228 detectable in the groundwater sample

Th228 detectable in 1 of the mine lease surface water samples (discharge channel)

Table 12 Downstream/Downgradient surface water pdf p 175

Ra226 detectable in all samples including upstream and 4 downstream – all very low

Th228 detectable in 1 surface water sample – very low

Table 13 Gamma Spec subset pdf p 177

U238, U234, Ra226, Po210, U235, detectable in groundwater

U238, U234, Ra226, Po210 U235 detectable in all surface water samples

Table 14. Upstream Surface Water pdf p 178

Ra226 in all but 1 sample

Po210 in the 2 samples where it was analysed

Table 15 Piezometers on Mine Site pdf p 178

All radionuclides analysed detectable but much less than WHO guideline

Table 16 Downstream surface water pdf p 179

Ra226 detectable in all samples

Po210 detectable in the 4 samples where it was analysed

Th228 detectable in 4 samples

Table 17 Gamma Spec subset pdf p 179

U238, U234, Po210, U235 detectable in groundwater

U238, U234, Po210, U235 detectable in all 5 surface water samples

Ra226 detectable in 2 surface water sample

Th228 detectable in 1 surface water sample

No supporting data reported: Field parameters apparently included pH, Conductivity, redox potential, DO and temperature. No reporting of "general observations" of surface water quality and flow. No mention of flow data or lake level data or GW levels.

There is no presentation of upstream-to-downstream surface water quality results. There is no presentation nor discussion of field parameters upstream-to-downstream and whether they might influence radionuclide levels in the water column. There is no discussion of whether sampling dates could have influenced the results via effects of river flow on dilution (I assume flows can vary widely depending on whether it is the wet or dry season).

There are no data describing the lake (Ambavarano) or pond (Abondrombe), including settlement basin bathymetry and whether the water column is mixed year-round, the relative size of the littoral zone, influence of connection with seawater, and seasonal water level patterns. These basic limnological characteristics are important factors influencing water chemistry as well as fate and transport processes (dilution, chemical speciation, sedimentation rates, deposition, resuspension, and food chain transfer). There is no discussion of how the weir has affected the lake's water quality or water level. See the lake sediment data for the stations SD4 – mid-lake, SD5 – north shore, SD14 mid-lake closer to MMM river mouth

Figures in the main body of the report for drinking water are difficult to decipher but appear to portray levels of individual radionuclides which are well below WHO guidance levels for individual radionuclides (Bq/L – vary with each radionuclide) and for dose (0.1 mSv).

This means that drinking untreated surface water or water from wells would not result in exceedance of WHO guideline levels – including the most sensitive individuals drinking water which had maximum concentrations (see error bars on the figure for drinking water on page 39/2111). The figures do not distinguish between surface and groundwater samples and the text does not explicitly state whether the 73 samples noted on the figure on page 39 is for all rounds of both SW and GW samples. IF all 15 SW stations yielded data for all 4 rounds = 60 samples. If all GW stations yielded data there would be 21 samples. Giving a total of 81 samples. Not 73.

Regarding upstream vs downstream vs mine site concentrations and the description of variability in water data as "high":

There are actually few direct site-to-site comparisons per radionuclide over sampling rounds.

Round 1. Table 3, (pdf page 168) where most results are less than detection so not informative re variation.

Table 4 (pdf page 169), which presents data from gamma spectrometry for specific radionuclides and the variability among sites is low.

Table 5 which is labelled surface water but is actually groundwater (pdf page 170) shows a distinct difference between mine groundwater and community groundwater for Ra226 Th232 and Th 228.

Round 2

Table 6 pdf page 171. Limited data. Groundwater vs surface water. Upgradient. GW 021 and GW022 don't exist. I assume this is GW02-1 and GW02-2 (duplicates of one community drinking water well). But SW 13 and SW 14 are downstream. No differences for Ra226 which was the only radionuclide above detection limits. Po210 was also measured in one ground water and one surface water sample with very little difference in levels - 0.0031 in SW and 0.0046 in GWRa

Table 7 pdf page 172 – ground and surface water at mine discharge point or on mine site. Groundwater higher in Ra226 than in surface water. Th228 measurable in mine groundwater but less than detection in surface water.

Table 8 pdf page 172 Downstream surface water. Ra226 detectable at 4 of 5 sites but only barely but two levels were 1 order of magnitude higher (SW07-2) or 2 orders of magnitude (SW01) than any of the upstream sites (Table 6) .

Table 9, pdf page 173 for 1 gw and 4 sw samples analysed by gamma spec – Ra226 at SW 9, 11, 12and the GW08 site was an order of magnitude higher than upstream/upgradient. Only one upstream SW and one upgradient Po result in Table 6 but Table 9 Po210 levels are lower than the levels in Table 6.

Round 3 Table 10: pdf page 174. One upgradient GW and 3 upstream SW. Ra 226 detectable at very low levels at 2 of 3 SW sites and at the GW site. Th232 and Th 228 detectable at 1 SW site (SW02) just barely above detection limit of 0.001. Th230 detectable at SW02 at 0.0044 (DL is 0.001).

Table 11 on pdf page 175. One GW and 5 SW sites "at mine discharge or on mine lease". Caption is confusing since the SW sample site numbers are appear to all be in the MMM River (Figure 1 pdf page 163). See also the figure on pdf page 39 which also does not include GW08 location but also shows the SW stations to be on the MMM River. Location of GW08 not shown on Figure 1 or on figure on pdf page 39 but is described in Table 2 as at Andrakaraka. I am assuming that the SW results in Table 10 are for the MMM River. R226 similar to upstream. Th230 just barely detectable in GW. Th232 just barely detectable in GW. Th228 0.0067 in GW (detection is <0.001-0.002).

Table 12 on pdf page 175. Caption is confusing again. The caption refers to downstream/downgradient but all samples are labelled SW. Downstream at 4 sites and one drinking water site (SW 03 is a small pond). SW all similar to upstream except perhaps SW04 which is a bit higher. The GW/drinking water Ra-226 is at upgradient levels. The only other result greater than detection was for Th228 at upstream levels.