Appendix I
Radiation Report

Radiation Assessment for the Coburn Mineral Sands Project

Introduction:

Heavy mineral sand deposits contain small quantities of the radioactive elements uranium and thorium, and their radioactive decay products. These radioactive elements occur mainly in the mineral monazite, an insoluble phosphate of the rare earth elements and thorium. They also occur (in much lower concentrations) in zircon, xenotime and leucoxene. (See e.g., Koperski 1993).

In past mineral sand mining and processing practices, reject material containing enhanced levels of radioactive minerals was sometimes disposed of in an uncontrolled way, and without prior planning, for example as fill in areas later developed for schools, shopping centres, or residential subdivisions. These instances sometimes resulted in unacceptable radiation doses to people, and thus required cleanup actions. As a result, there is now a requirement for planning and regulatory review to prevent such issues recurring.

At the outset it should be noted that the heavy mineral content of the ore to be mined in the Coburn Project (at 1.1%) is quite low compared with typical Western Australian mineral sand operations, and that the heavy mineral suite is in turn, very low in monazite content. As a result, the heavy mineral concentrate (HMC) to be produced in the wet concentrator is much lower in radionuclide content than the typical HMC produced at other WA sites. The thorium grade in the Coburn HMC is expected to be less than 140 ppm c.f. the typical WA level of 300 ppm, as quoted in Hewson and Upton, 1996.

As a consequence, radiation control issues are not expected to arise in mining or in the on-site wet separation plant operation. There is a likelihood of some low levels of radiation exposure in downstream processing in the operation of a dry minerals separation plant, mainly in the specific process stream that concentrates monazite waste. This however will be the responsibility of the purchaser of the Gunson wet plant HMC product and is beyond the scope of the Coburn Project as proposed.

Following surface radiation surveys on site, and based on the radionuclide content of the ore, it is confirmed that neither the open pit mining nor the operation of the wet concentrator will need radiation control. Thus the following text is given as background, with the proviso that it will become operationally more relevant should Gunson Resources decide at some time in the future to construct and operate a dry minerals separation plant. Such a plant would require its own approvals process.

Radiation:

Natural radioactivity was discovered (in uranium ores) by Henri Becquerel in 1896 and shortly thereafter his student Marie Curie noted that thorium ores also emitted radiation. She subsequently discovered the radioactive elements polonium and radium. Over the next decade, Ernest Rutherford identified the three types of natural radiation, namely alpha particles, beta particles, and gamma rays, emitted by uranium and thorium and their decay elements, and clarified the details of the thorium and uranium decay chains. (See Appendix 1 for the Thorium and Uranium decay chains.) Alpha particles have a range in air of about 2 centimetres and in solids or liquids of about 50 microns. Beta particles have a range in solids of a few centimetres, whilst gamma radiation is (depending on its energy) quite penetrating, with a range in solids of several to many centimetres.

Health risks arising from low levels of radiation:

At very high radiation doses to humans, for example above a few sieverts, radiation injury occurs, which manifests itself over a period of a few days to several weeks. At levels similar to environmental background (e.g., 2 or 3 millisieverts per year), and ranging up through doses which are in the range of

those delivered in medical diagnostic procedures (nuclear medicine tests and CAT scans, i.e., 5 to 20 millisieverts respectively), there is no direct evidence of either immediate or delayed health impact. However, it is known, based primarily on observations of the health outcomes of the survivors of the Hiroshima and Nagasaki bombings, and on the health outcomes to groups which had received large doses for medical purposes, that enhanced cancer risk occurs at higher doses, and it is cautiously assumed for radiation protection purposes that there may be some excess cancer induction, even at low doses. The International Commission on Radiological Protection (ICRP) assesses this possible excess cancer risk as about 0.005% per millisievert, which is to be compared with the normal population cancer induction of about 25%.

Doses and dose comparisons:

Natural background radiation dose arises from cosmic rays, from gamma radiation emitted by uranium, thorium, and potassium in the soil and rock underfoot, from radon in the air we breathe, and from radioactive elements in the food and water we ingest. Worldwide, the annual average natural background delivered to people from these components amount to about 2.4 millisieverts (ref. UNSCEAR 1988 p62). Of this, the cosmic ray component is in the order of 0.2 to 0.4 millisieverts per year. Natural background dose is extremely variable from place to place, with many areas in the world exceeding 10 millisieverts and a few even exceeding 100 millisieverts per annum. Radiation from human activities is controllable, and is limited by regulation to a maximum for radiation workers of 20 millisieverts per year, averaged over 5 years, with a limit of 50 millisieverts in any one year; and 1 millisievert per year for affected members of the public. These limits are applicable only to radiation arising from industrial, commercial, medical, or research "practices", and are not applicable to the uncontrollable natural background radiation, or to any radiation dose received for medical diagnostic tests or radiotherapy, or indeed to radiation arising from accidental releases or historical contamination.

Dose delivery pathways:

There are several *dose delivery pathways*, mechanisms by which radiation dose can be delivered to the human body, which potentially may need to be controlled, in uranium and thorium mining and processing. These are:
(i)   direct gamma irradiation or 'shine',
(ii)   inhalation of airborne long-lived alpha emitters,
(iii)   inhalation of radon and progeny, and
(iv)   ingestion of long-lived alpha emitters.

In the Coburn Project, doses received by workers will be very low, for reasons which will be explained below. (See below, Potential Radiation Impacts)

Regulatory regime:

International recommendations for radiation control are developed by the International Commission on Radiological Protection (ICRP) based primarily on the findings of the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), which continually reviews the world literature on radiation research, and publishes its findings on a regular basis. ICRP recommendations are taken up either directly by national regulatory bodies, or via model regulations based on ICRP advice, which are developed by the International Atomic Energy Agency (IAEA). Thus in Australia, ICRP and IAEA advice become melded into the advice generated by the national agency, which is the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA). This advice in turn is taken into account when State regulatory agencies rewrite their local Act and Regulations. Thus international and national recommendations feed into local (state) regulations which set limits, require licences, and set out processes for granting approvals to activities which cause radiation exposures and thus call for radiation monitoring and controls. The relevant regulation covering radiation control in the WA mining industry,

and applicable to the Coburn Project, is Section 16 of the WA Mines Safety and Inspection Regulation 1995.

The worldwide guidance in development of radiation safety regulations comes from ICRP's general recommendations published as ICRP Publication 60, published in 1991. This set of recommendations is being replaced with an updated set of recommendations, which have recently been released in draft form for public comment, accessible on ICRP's web page. However, the general impact will be minor, because there are not intended to be any significant changes in the limits (or 'constraints') on controllable doses.

The general radiation regulations applying in Australia to all industrial activities are guided by the Recommendations for Limiting Exposure to Ionizing Radiation; and National Standard for Limiting Occupational Exposure to Ionizing Radiation, 1995 (NHMRC 1995). These Recommendations and Standard were published as a single document initially in 1995 as Radiation Health Series #39, which was republished in 2002 as Radiation Protection Series #1.

The present WA regulations covering mining and processing operations were drawn up having regard for the Commonwealth Code of Practice for Radiation Protection in the Mining and Milling of Radioactive Ores 1987, and the companion Code of Practice on the Management of Radioactive Wastes from the Mining and Milling of Radioactive Ores 1982. These codes have been amalgamated and revised and will be reissued by ARPANSA as a *Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing*. This document is in final draft form and has recently been released for public comment. Again, it will not change the regulatory requirements substantially from those presently required, but rather provides a simplification and update of the present rules.

Description of Coburn Project

The Coburn Mineral Sand Project, owned by Gunson Resources Ltd, is based on a Heavy Mineral Sand (HMS) deposit known as the Amy Zone, a fossil dune-hosted sand deposit located inland from Shark Bay, approximately 250 km north of Geraldton. The Amy Zone is about 35 km long, and averages 1 km in width. It is between 10 and 40 metres thick and extends to the surface in places, surrounded by wide zones of lower grade mineralization. It contains an indicated and inferred resource of 710 million tonnes of ore averaging 1.4% heavy minerals (or 9.9 million tonnes of contained heavy minerals).

The ore contains very low levels of monazite (monazite content in the heavy mineral fraction between 0.1% and 0.2%). Median heavy mineral grain size is 120 microns.

The proposal is to mine the deposit via conventional strip mining, and produce for sale a Heavy Mineral Concentrate (HMC) at a minesite wet separation plant. Production is to ramp up to 14 million tonnes per annum (mtpa) of ore mined in years 1 and 2, with 28 mtpa from year 3 onwards.

At full production, 28 Mtpa of ore will give 224,000 tpa of Heavy Mineral Concentrate (HMC). Of the 224,000 tonnes of concentrate, the individual components will be:

ilmenite	120,000 t
zircon	60,000 t
leucoxene/rutile	30,000 t
waste	14,000 t

The mining is intended to proceed from South to North, over a mine life of approximately 20 years. All mining and concentrator facilities will remain in or near the pit and will be progressively relocated as mining proceeds. Wet concentrator reject materials will be deposited back into the pit for burial and rehabilitation which will proceed sequentially following mining.

Monazite being a heavy mineral will report to the HMC in the wet concentrator plant. Separation of monazite only occurs in subsequent downstream processing at the concentrate purchaser's offsite dry mineral separation plant (MSP), where it will then will report to the waste stream. Because the product from the wet concentrator will be sold to others for further processing, essentially all radionuclides will be sent off site in heavy mineral concentrate.

If Gunson Resources were to decide in the future to construct and operate its own Minerals Separation Plant (eg at Geraldton) then it is probable that the dry plant tailings would be required to be returned to the pit at Coburn. Such a decision would trigger a requirement for separate approvals and in particular for a radiation assessment and radiation management plan covering the specific requirements of the MSP and covering the disposal of the radionuclide bearing waste.

Potential Radiation Impacts:

The information available to date indicate the following, for the project as described consisting of mining of the Amy Zone and on-site wet concentrator operation:

(i)   There will be no chemical processing on site, hence there is no concern regarding solubilisation, and thus ongoing groundwater monitoring is unnecessary, unless dry mineral separation plant wastes are to be returned to the mined out area.

(ii)   The very low radionuclide content in ore, and the coarse median grain size (120 microns), together mean that airborne radionuclides in dust will be negligible as an environmental dose delivery pathway.

(iii)   Very low radionuclide content in ore also implies a very low local gamma radiation level, even where ore intersects the surface. We have estimated that the gamma component due to uranium and thorium in surface-exposed material to be in the order of ten nanosieverts per hour. This was supported by the recently-performed area gamma radiation survey, carried out as part of the Pre-Operational Environmental Radiation Baseline work. There will be a larger but still minor gamma source at the Heavy Mineral Concentrate stockpile(s).

Thus, one would only expect radiation issues to arise after separation of the HM concentrate at a downstream dry minerals separation plant, and in subsequent handling and transport of the dry plant waste, i.e., external to the present project. There will however be a need to assure that the doses to workers involved in loading of HMC product are within the public dose limit, and to ensure that there are no uncontrolled releases of contaminated equipment from site.

The expected monazite concentration in the HMC is 0.1 to 0.2%. At these low levels, gamma doserate over an extended source (such as a stockpile) of HMC product would be in the order of 0.5 to 0.7 μSv/hr., using the relationship reported in Appendix 3. At this doserate, and even assuming a worker spends all of his or her workhours physically on the stockpile, with no shielding (such as would be afforded by the structure of a front end loader, truck, or dozer), the worker's dose might only just exceed the Member of Public annual limit. Realistically however one would expect annual total doses of probably no more than 0.5 mSv to workers employed in the HMC stockpile area.

Dose Delivery Pathways:

As a matter of general principles, the potential radiological impacts of mining and processing of radionuclide bearing materials are:
(i)   emission of radionuclides in fugitive dust;
(ii)   emission of radon and thoron gas;
(iii)   release of dissolved radionuclides to groundwater or to surface waters; and
(iv)   direct gamma shine from stockpiles and uncovered ore.

These impacts can result in radiation doses to workers and to members of the public. In the case of the Coburn Project, all of these potential impacts are assessed to be negligible, however monitoring of the workers involved in stockpiling, loadout, and transport of the product heavy mineral concentrate to the purchaser's facilities would be advisable, for an initial period, to confirm the lack of hazard and fulfill 'duty of care' and due diligence obligations. The reasons why the radiological impacts of the Coburn Project are assessed to be so low are outlined below.

(i)   radionuclides in fugitive airborne dust:

This is most unlikely to be of any significance at all as a dose delivery pathway, for two reasons. Firstly, the as-mined mineral grain size is so large as to almost preclude the possibility of dust suspension in air (although attritioning can in principle produce finer particles); and secondly, the radionuclide content of the mineral grains is substantially below the average for other WA mineral sand deposits. However, at startup of wet plant operations, it would be prudent to perform air monitoring within the HMC product handling area, so as to confirm this assessment.

(ii)   emission of radon and thoron:

This is assessed as insignificant as a dose delivery pathway because of the low radionuclide content of the ore. It is also true that diffusion of radon and thoron from heavy mineral grains is minimal because of the tightly bound nature of the crystalline structure.

(iii)   release of dissolved radionuclides to surface or ground waters:

This is not possible in the situation under review because the material as mined is highly insoluble being deposited in dunes after concentration in an aqueous environment; and because no chemical processing takes place in the wet concentrator. Thus, the material remains insoluble throughout the process. Even in the case of tailings returned from a dry separation plant, the material would still be insoluble and immobile, and hence not a threat to the groundwater.

(iv)   direct gamma irradiation:

This has been found in the pre-operational baseline survey to be insignificant, as predicted, but may give a small dose to workers stockpiling and loading HMC, as discussed above. At commencement of the operations, these workers will be issued with radiation badges (e.g. "TLD" badges) to enable assessment of their doses. It is most unlikely however that even these "most exposed" workers will exceed the annual limit for members of the public (i.e., 1 millisievert), let alone approach the pro rata annual limit for radiation workers, which is 20 millisieverts. If results confirm that the doses are well below the limit for members of the public, then with approval of DOIR, the company may decide to cease issue of badges.

Other potential areas requiring management are in control of radioactive waste, namely any radionuclide-bearing scales or sludges arising from plant maintenance; plant area cleanup material (which would usually be returned to the process), and in control of transport, and planning for road transport spills following any vehicle accident.

Tailings: Wet plant tailings are not radioactive nor chemically mobile. Thus there is no radiation related constraint on their disposal. If Gunson Resources were to decide in future to construct and operate its own mineral separation plant at Geraldton (which is not presently proposed), then it may be required to return the tailings to Coburn for disposal within mined out areas. This would involve disposal of the (small) fraction of contained radionuclides within the original ore, essentially all of which will report to the monazite waste. This would present a minor hazard to workers which will be easily monitored and controlled, and would require that a Radiation Management Plan would be developed to address these monitoring and control issues in detail.

'Norm': (Naturally Occurring Radioactive Material) sludges: Any plant handling radioactive materials can 'build up' radionuclide bearing scales and sludges over time. For reasons discussed above (low initial concentration, no chemical processing) this is not likely to be a large or important issue at Coburn, but nevertheless it should be recognised as a possibility even if only as an issue for final end-of-project plant cleanup and disposal.

Transport: HMC trucked to the purchaser or to port for export will be exempt from the requirement to comply with the regulations as detailed in the Code of Practice for the Safe Transport of Radioactive Materials, issued by ARPANSA in 2001, which mirrors the international requirements issued by the International Atomic Energy Agency (IAEA). This exemption arises from the application of paragraph 107 (a) to (e) of the International Regulations, and of Clause 2.4 of the Australian Code. Monazite bearing waste which is to be returned to the pit for disposal may however need to comply with this Code, depending on the specific activity of the waste. Essentially, the Code requirements are that (a) the vehicles will need to be correctly 'placarded' as carrying radioactive materials, classified as Dangerous Goods Class 7; and (b) the drivers will need to carry "Consignor's Certificates" detailing the activity, Transport Index, and identity of the material, which will be classified as LSA-1, Low Specific Activity material. In addition, basic monitoring of the drivers will be necessary.

Baseline environmental radiation information and monitoring:

The Dept of Industry and Resources (DOIR) has issued a Guideline entitled "Pre-operational Monitoring Requirements for Mineral Sands Mining and Processing Sites", which was used in the planning of the baseline monitoring. The outline of the baseline program must be approved by the State Mining Engineer (SME). The Coburn Project Pre-Operational / Baseline Radiation Monitoring Program, as described in Appendix 2, was approved by DOIR in June 2004. The baseline data on area gamma doserates and surface soil radionuclide concentrations were collected in July. Pump test water samples were collected from the zone intended for project water supply, and from shallow aquifers.

Results of the Baseline Radiation Survey, together with assays of the co-located soil sample results, are presented in the Formal Report on the Baseline Environmental Radiation Survey. The results were generally consistent with the predictions, and indicative of a local baseline gamma radiation level of about 30 nGy/hr.

Radiation Management Plan, Monitoring and Controls:

The company has developed a Draft Radiation Management Plan (RMP) which includes basic dust monitoring and gamma surveys around the HMC stockpiles. The RMP commits to provide for basic monitoring of the workers and workplace relating to handling of the HMC product (the only area where enhanced radiation exposure is expected); dose assessments; worker training including Radiation Safety Manual; a waste management plan; and proposals for reporting. DOIR states that with no return of waste to site, "requirements would be minimal. We would expect an annual report listing amongst other things, the amount of HMC leaving site and where it went, the radiation levels around the HMC stockpile, and cleanup details once stockpiles are moved."

If a mineral separation plant were to be constructed at Geraldton, then a further RMP would be needed for it which would include description of site specific equipment, design, and procedures to minimise doses in the mineral separation plant; worker training including Radiation Safety Manual; environmental and occupational monitoring; and Radioactive Waste Management proposals including Restricted Release Zones and disposal undertakings.

Dose Assessment, Reporting and Consultation:

Doses of radiation workers must be assessed and reported to regulators and to workers. For a project such as Coburn, annual reporting would be appropriate. In addition as noted above, an annual report of quantities of HMC produced, and any plant waste disposed of to pit, will be prepared and reported.

Conclusions:

The Coburn Project will require only a basic level of radiation monitoring and reporting. The pre-operational environmental gamma survey shows very low levels of above-ground radiation, consistent with local sandy soils containing very low levels of uranium, thorium, and potassium. Even locations which had been identified as containing higher grades of heavy minerals showed gamma radiation doserates that were very low. This was due to the very low monazite content (and hence uranium and thorium content) in the heavy mineral suite.

Appendices:

Appendix 1:   Thorium and Uranium Decay Chains

Appendix 2:   Pre-Operational Environmental Radiation Monitoring Program and Results

Appendix 3:   Average concentrations of radionuclides and resulting gamma doserates

<h2>Appendix 1: Decay Chains</h2>

U-238 Decay Chain

Nuclide	Radiation	Energy (MeV)	Half-life
Uranium 238	α	4.2	4.5 billion yrs
Thorium 234	β γ	0.2 0.06, 0.09 (weak)	24 days
Protactinium 234	β	2.3	1.2 minutes
Uranium 234	α	4.7	250 000 yrs
Thorium 230	α	4.7	80 000 yrs
Radium 226	α γ	4.8 0.186 (weak)	1600 yrs
Radon 222 (gas)	α	5.5	3.8 days
Polonium 218	α	6.0	3 minutes
Lead 214	β γ	0.7 0.3, 0.35	27 minutes
Bismuth 214	β γ	1.0, 1.5, 3.3 0.6, 1.1, 1.8	20 minutes
Polonium 214	α	7.7	160 microseconds
Lead 210	β γ	0.016 0.047 (weak)	22 yrs
Bismuth 210	β	1.16	5 days
Polonium 210	α	5.3	140 days
Lead 206	------		infinite, lasts forever

Th-232 Decay Chain

Nuclide	Radiation	Energy (MeV)	Half-life
Thorium 232	α	4.0	14 billion yrs
Radium 228	β	0.06	6.7 yrs
Actinium 228	β γ	1.2, 1.7, 2.1 0.91, 0.96	6.1 hrs
Thorium 228	α γ	5.4 0.08, 0.21 (weak)	1.9 yrs
Radium 224	α γ	5.7 0.24 (weak)	3.6 days
Radon 220 (Thoron)	α	6.3	55 seconds
Polonium 216	α	6.8	0.15 seconds
Lead 212	β γ	0.35, 0.59 0.24, 0.3	10.6 hrs
Bismuth 212	β (64%) α (36%) γ (weak)	2.3 6.0 0.73	61 minutes
Polonium 212 (64%)	α	8.8	300 nanoseconds
Thallium 208 (36%)	β γ	1.3, 1.5, 1.8 2.6, 0.51, 0.58, 0.86	3.1 minutes
Lead 208		stable	infinite

Appendix 2:   Pre-Operational Environmental Radiation Baseline Monitoring Results

The purpose of this work was to establish baseline data on radionuclide surface concentrations and gamma radiation doserates over the proposed mining areas, and to obtain opportunistic groundwater samples from test bores for radionuclide analysis.   This survey was required by Section 16.6 of the Mines Safety and Inspection Regulations and was carried out in July 2004 following approval by the State Mining Engineer of the Preoperational Radiation Monitoring Program as proposed.

Gamma doserate survey:

A calculation of surface gamma doserate based on the very low reported monazite grades and hence very low U and Th grades indicated that local terrestrial gamma increment due to thorium and uranium in surface soils would be on average only a few nanosieverts per hour. These are very low doserates. For comparison, background cosmic radiation is quoted by UNSCEAR to be in the range of 30 nanosieverts per hour in mid-latitude locations, reducing towards the equator (ref. UNSCEAR).

To check these expectations, we carried out a broad area representative survey, taking soil samples and gamma doserate readings at 35 sites, primarily concentrating along pre-existing drill lines in the southern part of Amy Zone which is to be mined in the earlier years of the project, but including also sites along a transect continuing into the northern area of Amy Zone. Site locations were determined by GPS, and where possible were co-located with pre-existing drill holes. Soil samples were analysed by an external laboratory (Genalysis) for uranium and thorium under NATA certification. Gamma doserates were measured using calibrated scintillometer type survey instrumentation, namely a GR-130 Exploranium gamma spectrometer, on hire from Australian Radiation Services P/L. Calibration certification documents have been supplied to DOIR.

General gamma readings were in the order of 30 nanograys per hour, indicating very low terrestrial radiation increment above cosmic ray background. Instrument readings in microsieverts per hour were converted to micrograys per hour using the conversion factor for environmental doses of 0.7 Sv/Gy (see UNSCEAR 1993), as advised by Australian Radiation Services.

Soil assays were in the range of U = 0.22 to 0.50 ppm; and Th = 1.6 to 4.4 ppm. This is consistent with sandy soils elsewhere and is a result of virtually all uranium, thorium, and potassium having been leached out by weathering. A weak relationship was found between soil thorium assays and co-located above-ground gamma doserates.

Airborne radionuclides:

The very low surface soil radionuclide content and the large median Heavy Mineral grain size (quoted as 120 microns) both indicate that the airborne dose delivery pathway will be negligible. Also, there are no immediately adjacent residential areas. In addition, the DOIR guideline on pre-operational monitoring does not call for sampling other than in and adjacent to sites proposed for mineral separation plants. Again, this is because of the above reasons being generally applicable. As a result, air sampling was not conducted as part of the preoperational monitoring.

Water sampling:

No chemical treatment will take place in the wet concentrator, hence solubilisation is not a concern. As presently planned, wet plant heavy mineral concentrate will be trucked to Geraldton for sale.

The Company has carried out water sampling during test bore pump tests during August 2004, and also in January 2005. The sampling was primarily important to ensure non-scaling chemistry of the water to be used in the wet concentrator plant.

The analysis results from sampling the pump test of the aquifer which is proposed as the major water supply for site (DTB1) gave uranium below detection limit, and thorium at 0.07 mBq/L. The assays for the shallow aquifers gave uranium assays from 0.15 to 10 mBq/L and thorium from 0.15 to 70 mBq/L.

For comparison, the Australian Drinking Water Guide (ADWG 1996) guideline values for U and for Ra-228 (as arising from Thorium-232), which are U = 250 mBq/L; and Ra-228 = 500 mBq/L. These dissolved uranium and thorium concentrations are therefore all very low.

Appendix 3: Average concentrations of heavy minerals and of radionuclides in the product Heavy Mineral Concentrate, and calculation of resultant gamma doserates

Weighted by the uranium and thorium grades of the various mineral components, the HM concentrate will assay approx. U $\cong$ 60 ppm and Th $\cong$ 135 ppm.

Total (U + Th + decay chain progeny) activity concentration in the HM concentrate thus calculates out to something below 20 Bq/g.

Using the relationship reported by Botter-Jensen et al. and quoted in Sonter & Carter 2004, "Gamma Doserates over Land Contaminated with NORM, and Remediation Criteria", we note:

X (terrestrial + skyshine) = 0.58 μR/hr per ppm U + 0.29 μR/hr per ppm Th

Using an orebody HM grade of 1.1%, then in orebody U = 0.66 ppm, and Th = 1.5 ppm.

These then give a gamma above-ground doserate of
X = 0.44 μR/hr (from Th) + 0.38 μR/hr (from U) = 0.8 μR/hr. (in SI units, 8 nanosieverts/hr)

For comparison, normal sea level cosmic radiation at mid latitudes is quoted in UNSCEAR 1993 to be in the order of 30 nSv/hr, reducing with latitude towards the equator.

Similarly, doserates over large HMC stockpiles are estimated to be in the order of 0.7 μSv/hr..

References:

Hewson G and Upton H, Operational and Regulatory Aspects of the Management of Radioactive Wastes Arising from Mineral Sands Processing, Rad. Prot. in Aust. <u>14</u>, No. 3, pp 60-67, 1996.

Koperski J, Radiation Protection in the Mining and Milling of Mineral Sands, Rad. Prot. in Aust. <u>11</u>, No. 2, pp 46-52, 1993.

UNSCEAR 1988

Sonter & Carter 2004, Gamma Doserates over Land Contaminated with NORM, and Remediation Criteria (submitted for publication in Rad. Prot. in Aust..)

DOIR Guideline: Pre-Operational Monitoring Requirements for Mineral Sand Mining and Processing Sites, 1987

WA Mines Safety and Inspection Regulations 1995 (Section 16)

ICRP Publication 60, 1990 Recommendations of the International Commission on Radiological Protection, 1991.

ICRP Draft 2005 Recommendations, issued for comment, June 2004. (see www.icrp.org)

NHMRC 1995, Recommendations for Limiting Exposure to Ionizing Radiation; and National Standard for Limiting Occupational Exposure to Ionizing Radiation, 1995. (Published initially in 1995 as Radiation Health Series #39, and republished in 2002 as Radiation Protection Series #1)

ARPANSA 2001, Code of Practice, Safe Transport of Radioactive Material, Radiation Protection Series # 2, 2001.

Draft Mining Code, Draft Code of Practice and Safety Guide, Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing, ARPANSA, 2004.