# Appendix 7

## Assessment of Possible Radiological Impacts of the Browns Oxide Project in the Northern Territory

AUSTRALIAN NUCLEAR SCIENCE
AND TECHNOLOGY ORGANISATION
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**A SUMMARY**

**REPORT TO COMPASS RESOURCES NL**

on

# ASSESSMENT OF POSSIBLE RADIOLOGICAL IMPACTS OF THE BROWNS OXIDE PROJECT IN THE NORTHERN TERRITORY

by

D.E. Collier
J. Ferris

Prepared by ANSTO Minerals
General Manager: R.J. Ring

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ANSTO Minerals, PMB 1 Menai NSW 2234 Australia
Ph: +61 2 9717 3858 Fax: +61 2 9717 9129
E-mail: ansto.minerals@ansto.gov.au
Web: www.anstominerals.com

## SUMMARY

Compass Resources NL holds mineral leases in the Northern Territory and is planning to develop a base metals project on the site. The location of the leases and planned facilities is adjacent to the former Rum Jungle uranium operations site and radiological issues are consequently being considered. The project targets the near surface oxide metal values only. Any future projects targeting deeper or extended areas will be subject to separate environmental permitting.

Extensive environmental work has been carried out on the nearby Finniss River area, because of the previous impact of the Rum Jungle mining operation. This work identified the consequential impact to be primarily from heavy metals, notably copper, rather than from radioactivity.

Compass Resources NL approached ANSTO to prepare a report on the possible radiological impact of the Browns oxide project, with the objective of complementing the environmental approval process, and identifying potential issues related to radioactivity and the radiological impact of the Browns project on the environment.

This report is a summary of a broader study of the radiological impact of the Browns project. Further information can be obtained by referring to more detailed results being collated by the client on this subject.

The major findings are as follows:

- An environmental impact assessment concluded that there will be some environmental impact from the presence of uranium in ore, either dispersed as dust from mining operations or in tailings solids and solution. This can be appropriately managed in order to minimise the impact.
- The concentration of uranium in Browns oxide ore is very low, and would not be considered radioactive by regulators and would not be considered a uranium ore in its own right. Uranium could be separated from the process and recovered as a by-product, although this is not the intention. Thorium concentrations are much lower still.
- The total radiological dose rate to members of the general public, via the inhalation of ore dust, external gamma and other pathways, from mining and ore processing activities, was calculated to be less than 0.04 mSv/y, based on very conservative assumptions. This is well below the allowed exposure limit for a member of the public of 1 mSv/y. The total dose to workers from all pathways in mining and ore handling and crushing was less than 0.3 mSv/y and is also well below the allowed exposure limit for a member of the public.

Baseline radiological data is limited, but will continue to be collected by Compass Resources as the project development plan progresses. This will consist of reviewing existing data, further analysis of bore waters and carrying out some radiological measurements on site.

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## GLOSSARY OF TERMS

**ALARA**: As low as reasonably achievable, taking into account economic and social factors

**AMAD**: Activity Median Aerodynamic Diameter

**ANSTO**: Australian Nuclear Science and Technology Organisation

**ARPANSA**: Australian Radiation Protection and Nuclear Safety Agency

**Annual Effective Dose**: The total annual radiation dose averaged over the whole body.

**Becquerel** (Bq): Name for the SI (System Internationale = International System of Units) unit of radioactivity, equal to one transformation per second.

- supersedes the curie (Ci) where 1 Bq = 27 pCi ($2.7 \times 10^{-11}$ Ci)

**BSS**: IAEA Basic Safety Standard

**CCD**: Counter current decantation

**Committed Effective Dose**: CED, the effective dose from the intake of a radioactive material integrated over 50 years for an adult and 70 years for a child in $\mu Sv\ a^{-1}$. The dose is assigned to the year of intake.

**DNA**: Delayed neutron analysis

**EIS**: Environmental Impact Statement

**EPBC**: Environment Protection and Biodiversity Conservation Act

**Gray**: Gy, SI unit of absorbed dose, equal to 1 J/kg

**IAEA**: International Atomic Energy Agency

**ICRP**: The International Commission on Radiological Protection

**NAA**: Neutron activation analysis

**NLC**: Northern land council

**NOI**: Notice of Intent

**NORM**: Naturally occurring radioactive material

**PER**: Public Environmental Report

**PPE**: Personal protective equipment

**Radioactive Ore**: Commonwealth Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores (1987) - "An ore or mineral which is exploitable for its content of uranium or thorium or their daughter products". In the proposed National Directory, any mining material containing any naturally occurring radionuclides with a concentration exceeding scheduled values will be considered radioactive for regulatory purposes.

**RIA**: Radiological Impact Assessment

**RRR**: Radioecological Risk Assessment

**Secular equilibrium**: A decay chain is in secular equilibrium when all radionuclides contribute equally to the total activity due to that chain

**Sievert (Sv)**: Name for the SI unit of equivalent dose and effective dose, equal to 1 J $kg^{-1}$.

- 1 millisievert (mSv) is equal to one one-thousandth of a sievert
- 1 microsievert (μSv) is equal to one one-millionth of a sievert

**SX**: Solvent extraction

**$Th_{nat}$** or **$U_{nat}$:** Thorium-232 or uranium-238 is present in equilibrium with its complete decay chain and that a concentration limit for the parent radionuclide is such that it is understood that the whole decay chain is present.

**UNSCEAR**: United Nations Scientific Committee on the Effects of Atomic Radiation

**WGC**: World Geoscience Corporation

## 1. INTRODUCTION

Compass Resources NL holds mineral leases in the Northern Territory. The company plans to develop a copper nickel cobalt mine and processing operation at the Browns site. Compass plans to complete a "Public Environmental Report" by the end of August 2005.

This report addresses issues arising from the presence of low concentrations of naturally occurring radioactivity in the ore from the Browns mineral lease areas (a total of 1.7 sq km), adjacent to the old Rum Jungle uranium mining area. The report assesses the impact of the presence of naturally occurring radioactivity in Browns ore on the environment. One of Compass' key objectives is to ensure that operations are undertaken in a manner that minimises any impact on the adjoining community and/or local flora and fauna.

The presence of naturally occurring radioactive material (NORM) in ore and the ground water supply, and its distribution in metallurgical processing, may require that appropriate measures be taken to minimise the exposure of the workforce and the public, and to minimise any environmental impact from tailings, waste liquors, airborne emissions etc.

The presence of NORM in ore and/or concentrates frequently results, for example, in volatile radionuclides, such as $^{210}$Po and $^{210}$Pb, reporting to recycled dusts associated with thermal/pyrometallurgical processes and the accumulation of radium radionuclides in scales in hydrometallurgical and water treatment circuits. If this occurs, such dusts and scales require that appropriate handling, transport and disposal procedures are followed. No thermal / pyrometallurgical processes are proposed for the Browns Oxide Project.

The presence of radioactivity in end-products being transported and marketed overseas is also becoming of increasing importance, because of more stringent exemption concentrations specified by the regulators/licensing authorities. These exemption concentrations are the basis for products exported from Australia possibly being classified as radioactive.

Although the concentrations of $^{232}$Th and $^{238}$U decay chain radioactivity are low in Browns ore, as a starting point to investigate the above issues, Compass Resources has analysed for NORM in ores, process intermediates and end products during the project's development. The results of this analytical work are contained in ANSTO reports and technical notes.

This report provides an assessment of the likely impact on the environment of the low concentrations of naturally occurring radioactivity in the proposed Browns project.

## 2. OBJECTIVES AND SCOPE OF WORK

The objective of this study is to prepare a short report on "The radiological impact of the Browns project" to support the "Public Environmental Report". This work will support the approvals process to mine near surface oxide ore (approximately the top 20 m), and to process this ore by mineral processing and hydrometallurgy to produce copper metal or copper sulphate and copper and nickel hydroxides or sulphides.

The following tasks were undertaken:

- review existing Compass and ANSTO analytical data on radioactivity in Browns project samples;

- discussions with Compass re proposed project – including the technology employed and flowsheet;
- Assays of samples: These included:
  - further ore samples;
  - site bore waters; and
  - acidic leach solutions. This was the only downstream product available within the time frame of this work.
- estimate radionuclide deportment in process and to end-products;
- dose calculations for realistic exposure scenarios;
- provide a background to international and Northern Territory regulations relating to the management of NORM in regard to environmental impact;
- a review of radiological impact – environmental (i.e. surrounding ecosystem), occupational and public radiological doses associated with the mining and production of ore at Browns project;
- provide advice on potential commercial concerns, *e.g.* copper and nickel/cobalt products quality, as required by the client;
- internal peer review of draft report at ANSTO Minerals; and
- final report with recommendations for management measures arising from the presence of NORM (if required). This was subject to discussions with the client.

The review of the potential radiological consequences associated with the processing of Browns ore including mineral processing, hydrometallurgy and waste disposal aspects rely on information provided by the client.

The analytical techniques used included delayed neutron counting (DNA for uranium), neutron activation analysis (NAA for thorium) and gamma spectrometry.

## 3. PROJECT DESCRIPTION

A Notice of Intent by the client [Compass 2004] documents the mining and metallurgical extraction processes proposed for the Browns oxide project. The mining leases held by Compass Resources NL, as shown in **Figure 3.1**, are located some 8 kilometres north of the town of Batchelor. Local road, power, rail and township infrastructure is shown in **Figure 3.2**. The tenements are some 15 kilometres from the Litchfield National Park and are south of the East Branch of the Finniss River system. They are approximately one kilometre from the former Whites copper and uranium mine and two kilometres from the former Dysons uranium mine. These, together with the Intermediate copper mine, are collectively referred to locally as "Rum Jungle".

## 3.1 Mining

Weathered oxide ore will be selectively mined by open pit. The oxide ore will be separated from overburden and underlying massive sulphide ore by selective mining. The surrounding geological structures are described briefly in the Notice of Intent [Compass 2004]. Most waste rock will be net acid consuming with any potentially acid forming material managed in the tailings storage facility embankment.

## 3.2 Metallurgy

Browns oxide ore will be crushed and milled into a slurry, which will then be leached with sulphuric acid to extract the contained copper, nickel and cobalt metal values.

The slurry from leaching will be treated by countercurrent decantation (CCD) or other solid/liquid separation method to separate leach solution from barren tailings solids. A washing efficiency of 95% will be achieved, with any remnant acid being consumed by the net acid consuming gangue minerals in the tailings. The washed solids will be pumped and deposited in a purpose designed tailings dam.

Copper will be recovered from the leach solution by solvent extraction (SX) and electrowinning and nickel and cobalt will be recovered from treated SX raffinate by neutralisation/precipitation using magnesia (MgO). Copper will be produced as LME grade cathode copper and/or niche market copper sulphate.

A simplified flowsheet is shown in **Figure 3.3**. Testwork by Compass indicates that the wash efficiency on tailings will be in excess of 95% and that remnant acid will be consumed by net acid consuming minerals remaining in the leached solids. It is possible that the flowsheet will develop further to also include recovery of lead carbonate minerals by gravity methods.

## 3.3 Waste Management

As no thermal processes will be used, airborne dispersion of gases, dusts and fumes containing radionuclides will be limited to potential sources of ore and waste dust from mining, ore preparation and tailings deposition.

### *3.3.1 Waste rock management*

Overburden low grade material with a low degree of mineralisation, including constituents, which could contribute to any acid mine drainage and therefore mobilisation of other trace contaminants including radionuclides, will be used to construct the purpose designed tailings storage facility.

### *3.3.2 Tailings management*

Compass has indicated that the tailings will consume residual acid after placement rather than generate acid. Recovered water will be recycled to the plant from the tailings dam.

Process liquor neutralisation may be required to allow some release of excess treated process water. The solids waste from water treatment will be predominantly an iron hydroxide/gypsum precipitate containing minimal concentrations of uranium, $^{234}$Th, $^{230}$Th and $^{226}$Ra.

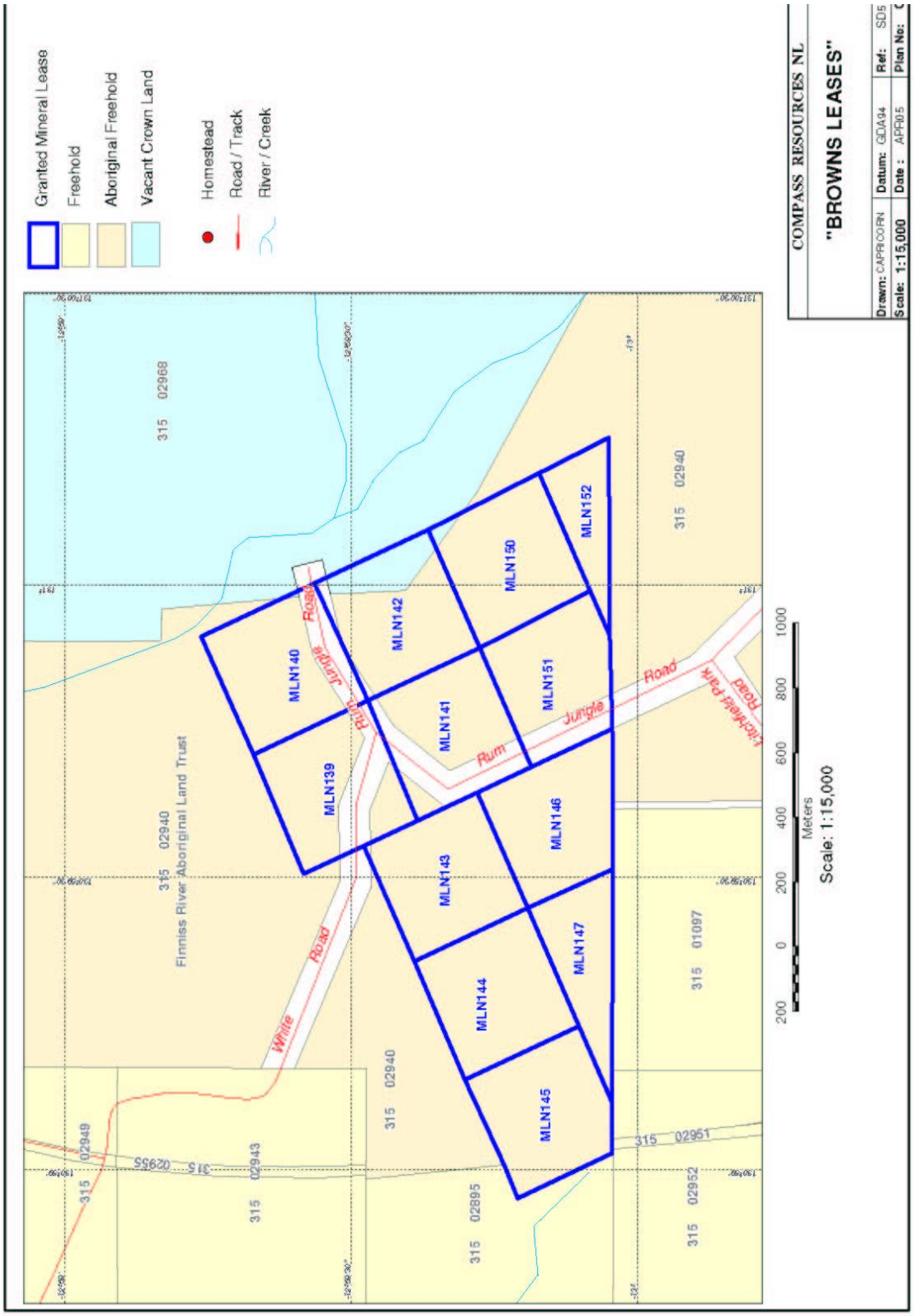



**FIGURE 3.1 Compass Resources Mining Leases**

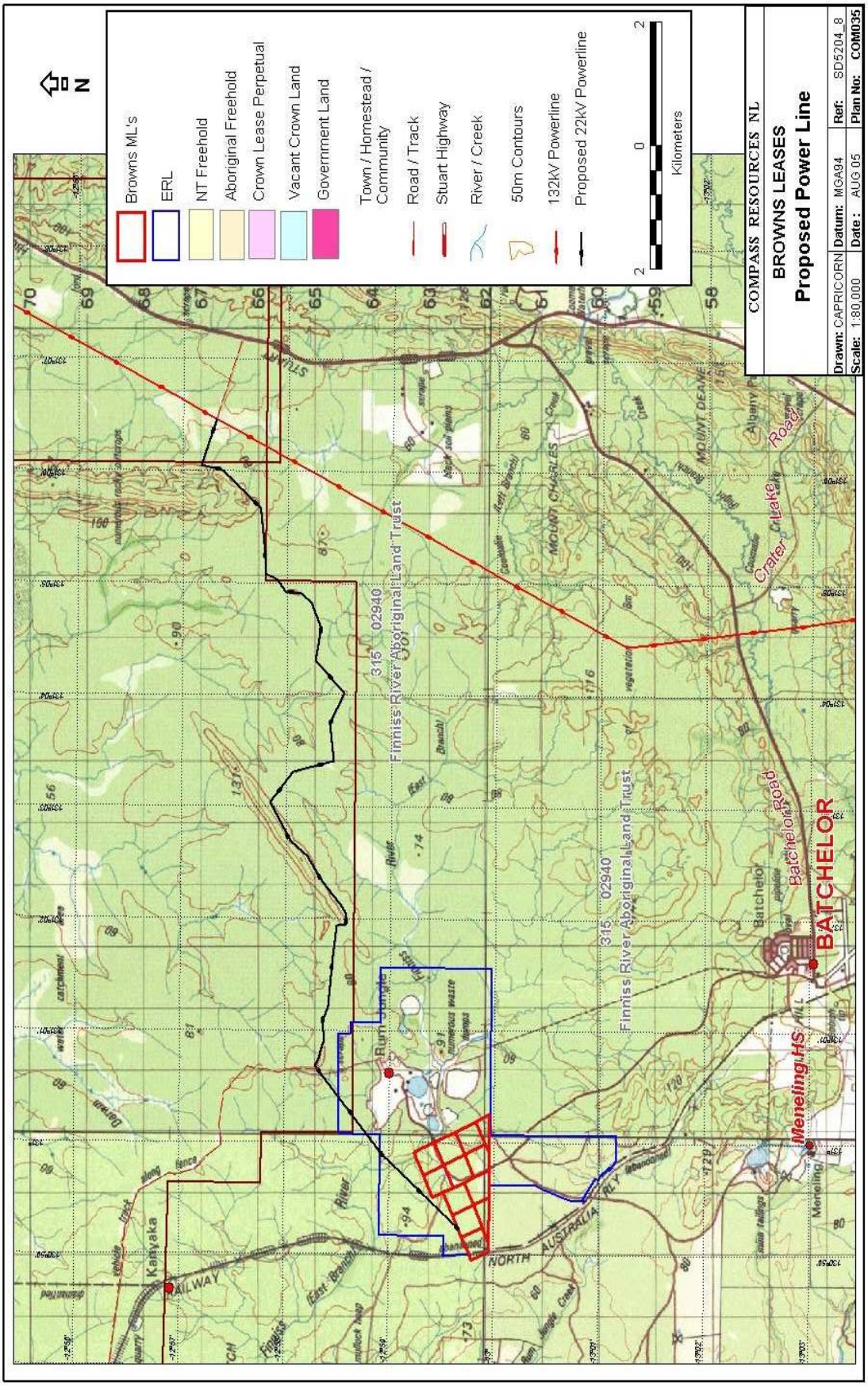



**FIGURE 3.2 Area Map**

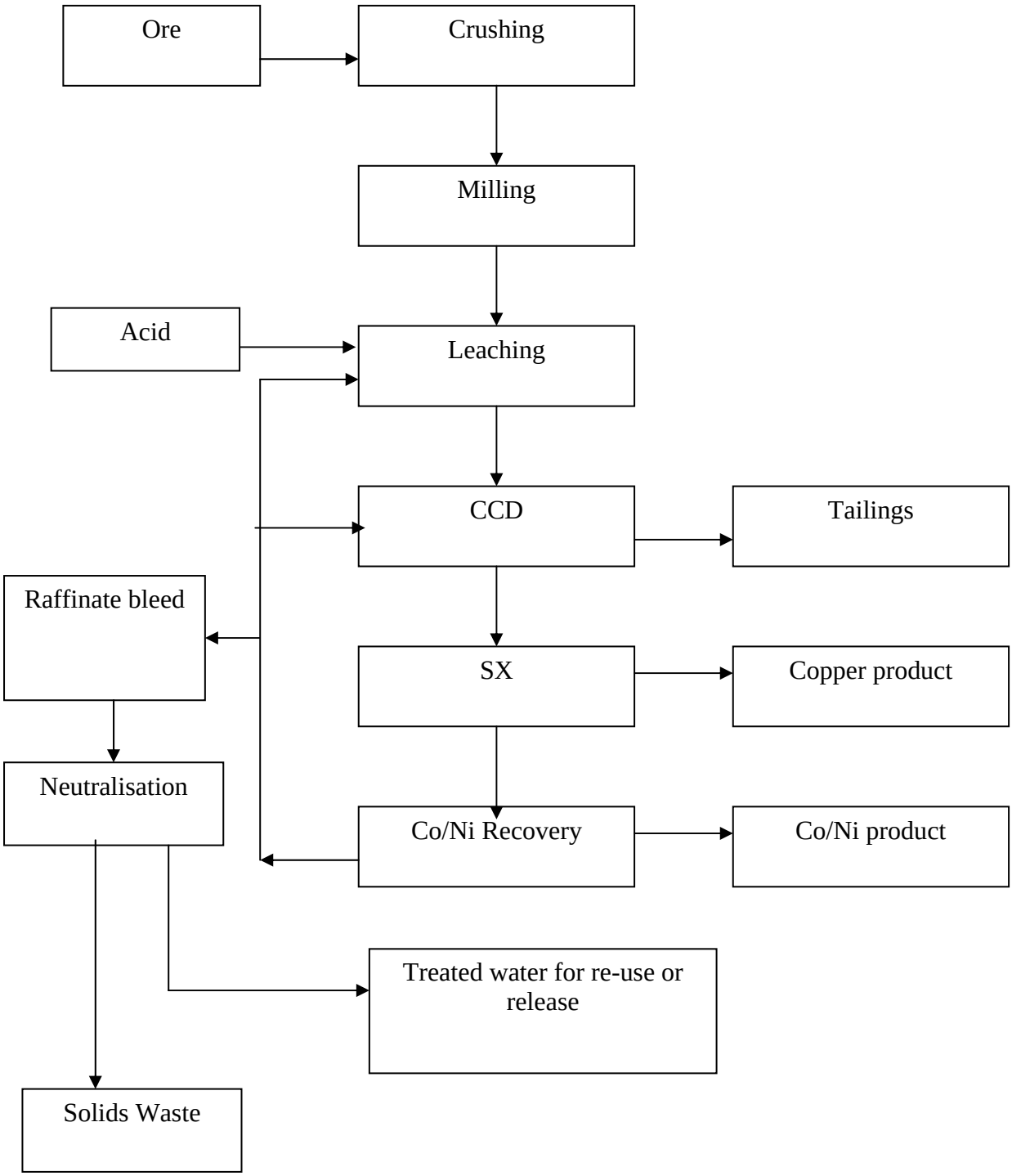



**FIGURE 3.3 Simplified Process Flowsheet**

### *3.3.3 Water management*

Variable rainfall conditions need to be accommodated under the extremes of water availability, *i.e.* periods of excess water and water shortages. Browns leases are located on a watershed. Some water flows to the east branch of the Finniss River, downstream of Rum Jungle, while some flows to the south.

Best practice water recovery and use will include the separation of waters of various quality.

Potable and ground water suitable for processing are available locally.

## 3.4 Environment

The Notice of Intent [Compass 2004] identifies the main environmental issues for the project. It emphasises the need to have clear base-line data on the project area, particularly in the light of legacy issues associated with the former Rum Jungle operations. For this reason, base-line data on water quality and future monitoring of surface and bore waters will form part of the ongoing Mine Management Plan. Acid storage will require particular attention through installation of appropriate bunds, because of its potential to mobilise pollutants, including radionuclides, if spilt.

There is substantial published information available on the local flora and fauna, as well as on the pre-existing environmental effects of the Rum Jungle copper/uranium mine and the efficacy of its remediation.

The main areas of environmental impact from the Browns project will be the pit, the processing plant and the wastes.

The areas of potential broader environmental impact from the project, identified in the NOI, will also have potential radiological impact and include;

- Water – any uranium and thorium and long lived progeny;
- Air – any radon / progeny;
- Dust – U and Th decay chains. General controls placed on dust in mining, haulage and crushing will restrict any radiological impact due to exposure from this pathway;
- External gamma - U and Th decay chains.

## 4. REGULATIONS CONCERNING RADIOACTIVITY

The Commonwealth Minister must be referred to for advice when dealing with uranium mining and processing in the Northern Territory [Northern Territory 2001]. In some circumstances, a project application may become subject to the Commonwealth Environment Protection and Biodiversity Conservation Act 1999. From a Federal government perspective, a Commonwealth Referral has been made and the Browns project is not a "Nuclear Action" under the Commonwealth EPBC Act *(http://www.deh.gov.au/epbc/matters/nuclear.html*), because Compass are not proposing to recover the small quantity of associated uranium for sale *per se*.

Regulations concerning radioactivity have a definition of what is a radioactive material for the purpose of those specific regulations. This usually involves "levels" of both 'concentrations' of radioactivity as well as 'quantities' of radioactivity. The regulations may also state the nature (ores, concentrates, residues etc) of the materials included in the regulations.

Radiological issues require reporting in accordance with the mine management plan, together with other environmental matters, to an extent determined by the regulatory position taken for a specific site and its local conditions.

Regulations are based on international dose limits allowed for members of the public and the workforce.

### 4.1 International

The International Commission on Radiological Protection (ICRP) makes recommendations on the control of exposure to radioactivity. These recommendations are then used by the International Atomic Energy Agency (IAEA) to update international regulations and provide guidelines and technical documents to assist regulators around the world.

#### *4.1.1 IAEA Basic Safety Standard*

The exemption levels[1] in the IAEA Basic Safety Standard (BSS) [IAEA 1996] have been adopted widely by regulators around the world. The exemption concentrations are for 'moderate' quantities of material (< 1 tonne). The exemption concentration for larger quantities of traded commodities in the IAEA Safety Guide RS-G-1.7 [IAEA 2004] is 1 Bq/g for <u>any</u> radionuclide in the $^{232}$Th or $^{238}$U decay chains.

### 4.2 National

The application of radiological protection regulations is currently not uniform throughout Australia. The development of uniform national radiation protection legislation became one of the responsibilities of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA), when it was established as Australia's national radiation protection body to administer the ARPANS Act (1998) and Regulations [ARPANSA 1999]. The new guidelines are contained in the National Directory for Radiation Protection (the Directory, Edition 1).

[1] The levels are both concentrations and quantities of contained radioactivity. If either are less than the exemption value, the practice does not need to be regulated. As a miner is usually dealing with large quantities of materials, the quantity level is easily exceeded and the only avenue for no regulation is for the concentration to be less than the exemption value.

The exemption levels in Commonwealth Regulations are based on the BSS values for individual radionuclides. A derived total concentration exemption limit can be calculated, when mixtures of radionuclides are present, depending on the scenario. A material is exempt (from regulatory consideration), if the concentration of a radionuclide is less than the exempt concentration for that scenario. The concentration exemption value, for example, proposed internationally for trade in large quantities of commodities is 1 Bq/g for any NORM radionuclide [IAEA August 2004].

#### *4.2.1 Transport Code*

One scenario is the transport of materials, which may contain radioactivity, from the mine site. This is covered by the national Code of Practice RPS2 [ARPANSA 2001], which, to a large extent, has also been incorporated into local regulations. This Code is based on the IAEA Transport Regulations and the BSS. The Australian Code has a broader definition of NORM and allows a 10 times factor to be applied to the Transport Code exemption limits, when applied to the transport of natural and processed ores and concentrates (NORM).

### 4.3 State Jurisdiction - Northern Territory

The Radiation (Safety Control) Act [Northern Territory 1999] is currently in force in the Northern Territory and provides some regulatory guidance in respect to issues such as general radiation safety management and disposal of wastes. The Act is of limited application to the mining and management of large quantities of material containing NORM.

The Northern Territory also has an Act for the regulation of transport of radioactive “ores and concentrates” [Northern Territory 2002] however this has been superseded by the newer Code of Practice based on the ARPANSA Code and the IAEA Standard.

The Mining Management Act 2001 [Northern Territory 2001] specifically addresses environmental management at a mine site. The Mining Management Plan, as required of all operations, must address environmental issues. This includes radiological issues. The close proximity of the project to the former Rum Jungle uranium mine site is most likely to flag a “potential” radiological issue. A Radiation Management Plan could be requested as part of the Mine Management Plan, but would be commensurate with the size and potential impact of the operation.

The Northern Territory government is supportive of the current trend towards the application of uniform regulations across Australia relating to radioactivity, as reflected in the National Directory [ARPANSA 2004]. It has adopted the Federal Code of Practice for the Safe Transport of Radioactive Material [ARPANSA 2001] based on the international regulations, but some older Codes for Management of Radioactivity are still currently in use, *e.g.* when considering occupational exposure.

The Environment Assessment Act 1982 [Northern Territory 1994], and its associated administrative procedures, establish the requirements for reporting on projects expected to have an environmental impact. These are usually in the form of a Public Environmental Report (PER) or Environmental Impact Statement (EIS). Although this process is administered through the Department of Infrastructure, Planning and Environment, other

Departments (including Health, Conservation and Mining Departments) make contributions to this approval process, based on their specific areas of expertise/responsibility.

The Mining Management Act addresses the protection of the environment on mining sites by achieving best practice management in accordance with best practice environmental standards. The Northern Territory government authorises and monitors mining activities using a Mine Management Plan, which includes systems to address environmental issues. This includes the mine closure and site rehabilitation process. Exemption values at mine sites are currently those in existing Codes of Practice [NHMRC 1982, 1987], which is based on dose and ALARA. The new National Code will affect this and is expected to be introduced in 2006.

### 4.4 Environment

A basis for the protection of the environment from low level naturally occurring radioactivity is currently being established internationally. The International Commission on Radiological Protection [ICRP 1990/91] has, in the past, assumed that standards of control, needed to protect man, would also ensure that other species are not put at risk. This approach and philosophy has recently changed [ICRP 2003] and moved towards the introduction of a clearer policy for explicit radiological protection of the environment. The ICRP is developing recommendations to assess radiation effects on non-human species. The new objective [Johnston 2005] is to safeguard the environment, by preventing or reducing the frequency of effects likely to cause early mortality or reduced reproductive success in individual flora and fauna, to a level, where any effects would have a negligible impact on conservation of species, maintenance of biodiversity, or the health and status of natural habitats or communities. The international scientific community is developing tools to facilitate this philosophy, for example via FASSET (Framework for Assessment of Environmental Impact) and ERICA (Environmental Protection from Ionising Contaminants (EPIC) programmes (http://www.erica-project.org/) funded within the European Community .

### 4.5 Summary

The regulation of naturally occurring radioactivity in the mining industry is currently changing. The regulators are aware of international trends to include NORM in new Codes and regulations and this is underway in Australia.

The adoption of the IAEA Basic Safety Standards and the national harmonisation of the regulations are desirable for regulatory management of NORM, however the changes are also a reflection of the currently increasing focus on NORM waste legacy around the world. The process of adopting the regulatory changes will result in increasing scrutiny of operations likely to have radioactivity in excess of the new regulatory defined concentrations in ores, processes and products.

The methods and requirements on how exposure to NORM will be managed at a specific site is ultimately a regulatory decision.

## 5. RADIONUCLIDE DATA AND DEPORTMENT

The Browns oxide project lies within one kilometre of areas known to contain uranium, as demonstrated by aerial radiometric measurements shown in **Figure 5.1**. Uranium, copper, nickel and lead were mined from the adjacent Rum Jungle site between 1950 and 1971. The impact of the uranium mine, its subsequent rehabilitation in the early 1980s and follow-up studies on the effectiveness of rehabilitation are well documented [Davey 1975; Kraatz and Applegate 1992; Kraatz 1998; Markich and Jeffrey 2002].

An airborne gamma-ray survey of Rum Jungle was carried out by WGC in July 1996. The images produced by World Geoscience Corporation (WGC) clearly show elevated count-rates around the Rum Jungle mine site, Rum Jungle South Mine and the East Branch of the Finniss River downstream from the confluence with Old Tailings Creek. Elevated uranium daughter concentrations in the East Branch of the Finniss River are probably due to the accumulation of weathering products from before mining, or tailings washed into the river during operation of the mine. Dose rate maps are increasingly needed for environmental monitoring and baseline studies.

The WGC dose rate map shows that the dose rates at the site are comparable to the natural activity at many locations in the region. A comparison between the absolute values of the dose rates, as deduced from the airborne survey, with ground measurements at the Rum Jungle Creek South site were in agreement, in the range of 20 - 30%.

As the Browns project is downstream from the former Rum Jungle uranium mine area, any impact from the Browns project needs to be determined in the context of the ongoing environmental effect from acid drainage generated on the Rum Jungle site, and could be complicated by the failure of covers on the old Rum Jungle mining areas. Possible future extension of the Browns project into the old mine areas, with subsequent rehabilitation using more modern techniques, based on the extensive data available, could be a preferred outcome for the overall rehabilitation of the area.

### 5.1 Project Samples – Source and Treatment

Early uranium assay results for Browns oxide composite ore samples analysed by ANSTO are given in **Table 5.1**. These samples were composites of drill holes drilled along the strike length of the proposed oxide mine and composited into samples typical of the life of mine ore grade and lithologies. The samples were analysed for uranium using delayed neutron analysis (DNA). Further analyses (**Appendix B**), undertaken as part of this study, are shown in **Table 5.2**.

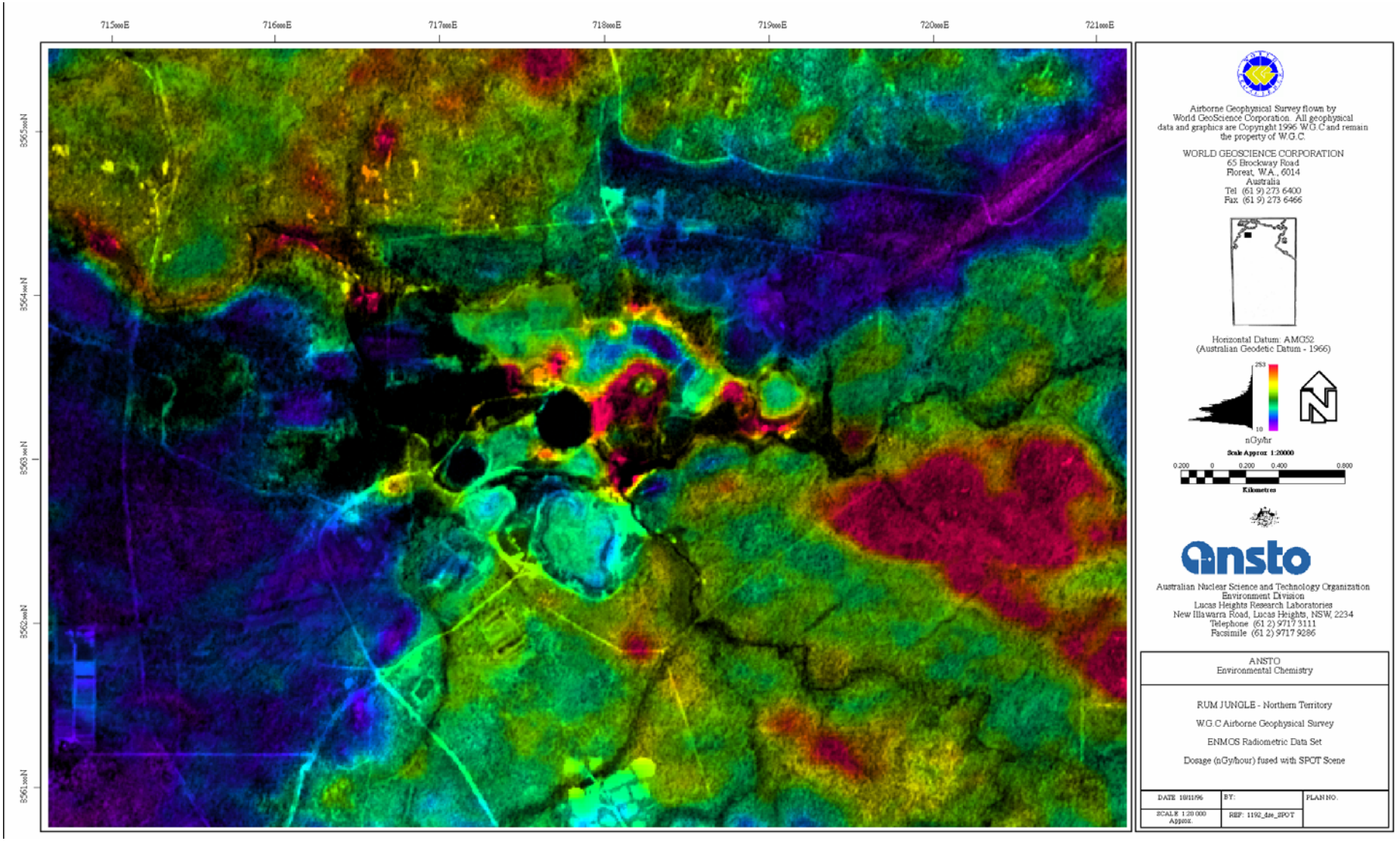



**FIGURE 5.1 Radiometrics over the Browns Project Area**

**TABLE 5.1**

**Uranium Content of Compass Composite Samples Previously Assayed by ANSTO**

| ANSTO identity | Client<br>Sample Description | Radioactivity Content | | | |
|---|---|---|---|---|---|
| | | (ppm U) | (%$U_3O_8$) | Bq/g U | Total Activity * (Bq/g) |
| Comp-020305-1 | Browns carbonate composite 1 | 19.7 | 0.0023 | 0.24 | 3.40 |
| Comp-020305-2 | Browns black shale composite 2 | 10.7 | 0.0013 | 0.13 | 1.85 |

* for the total decay chain - assuming all the $^{238}U$ decay chain progeny are in secular equilibrium.

**TABLE 5.2**

**Analyses Proposed for this Study**

| Sample | No. off | Analysis |
|---|---|---|
| Ore | 10 solids | DNA (U)<br>NAA (Th) |
| Tailings / leach residue | 2 solids | DNA (U)<br>NAA (Th) |
| Site bore water | 3 liquids | ICP MS (U & Th)<br>Gamma (progeny) |
| Leach solution | 4 solutions | ICP MS (U & Th)<br>Gamma (progeny) |

The ore samples previously assayed, as shown in **Table 5.1**, were composites from five widely spaced drill cores. The more recent assays of ore samples obtained from each of the drill holes are given in **Table 5.3**. Drill hole locations are shown in **Figure 5.2**. The drill core samples were assayed in duplicate for uranium. XRF assays by UNIQUANT and neutron activation analysis (NAA) results for thorium are given in **Appendices C1** and **2**. Selected core samples were also analysed by gamma spectrometry.

**TABLE 5.3**

**Uranium Content of Ore Drill Core Samples**

| Sample | ANSTO ID | Depth (m) | Uranium Assays (ppm U) | |
|---|---|---|---|---|
| | | | | Duplicate assay |
| Hole BD02 - 59492 | Comp-250505-1 | 4-5 | 8.4 | 8.1 |
| Hole BD02 - 59498 | Comp-250505-2 | 9-10 | 23.7 | 23.5 |
| Hole BD05 - 59546 | Comp-250505-3 | 4-5 | 12.1 | 11.8 |
| Hole BD05 - 59552 | Comp-250505-4 | 9-10 | 10.6 | 10.9 |
| Hole BD06 - 59573 | Comp-250505-5 | 4-5 | 12.8 | 12.7 |
| Hole BD06 - 59579 | Comp-250505-6 | 9-10 | 8.5 | 8.3 |
| Hole BD07 - 59584 | Comp-250505-7 | 4-5 | 9.7 | 10.5 |
| Hole BD07 - 59589 | Comp-250505-8 | 9-10 | 8.5 | 8.2 |
| Hole BD08 - 59607 | Comp-250505-9 | | 16.8 | 16.9 |
| Hole BD08 - 59611 | Comp-250505-10 | 9-10 | 28.6 | 27.9 |

Bore hole water samples were collected from the locations shown in **Figure 5.3**.

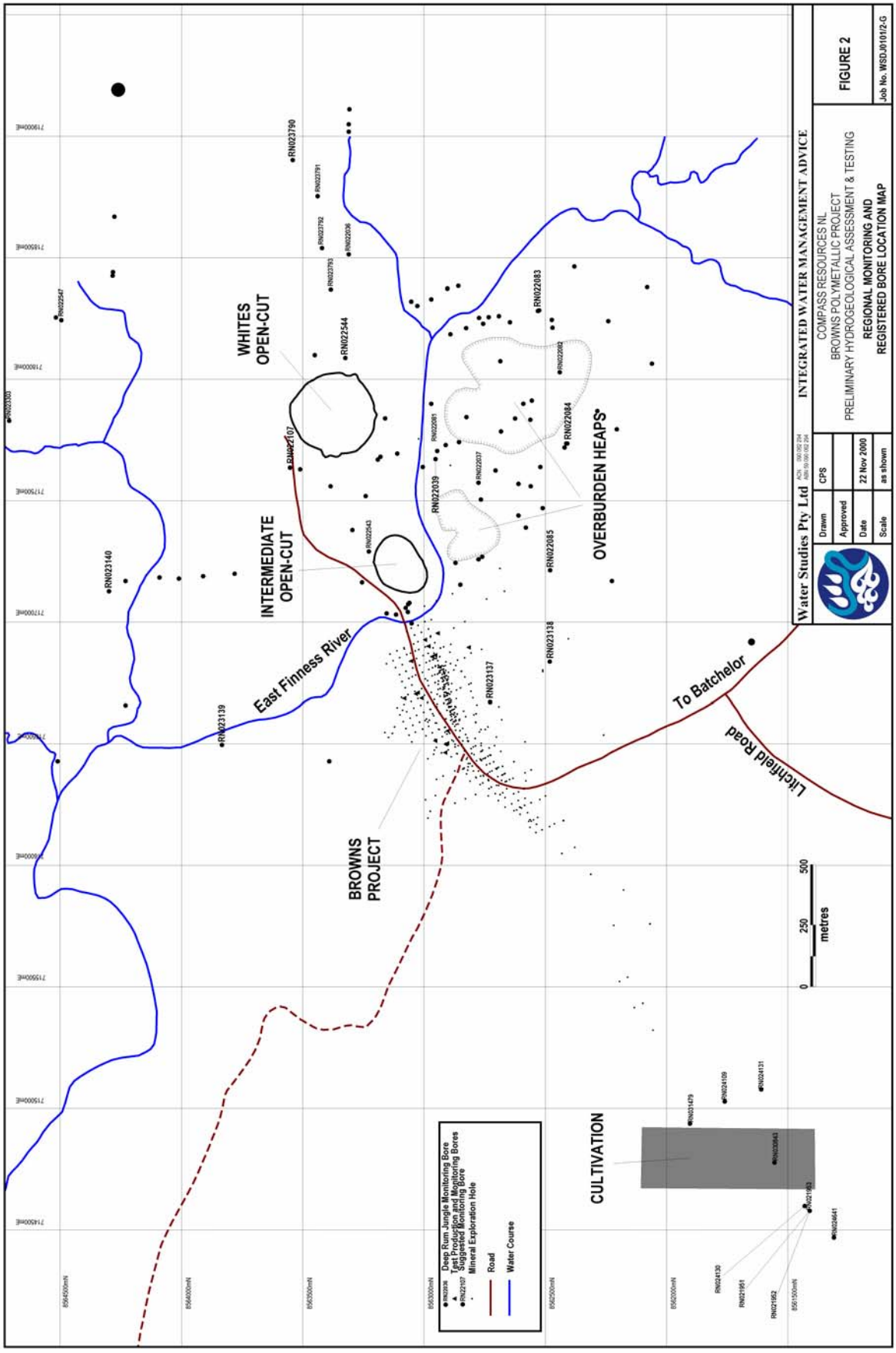



**FIGURE 5.2 Ore Body Drill Hole Locations**

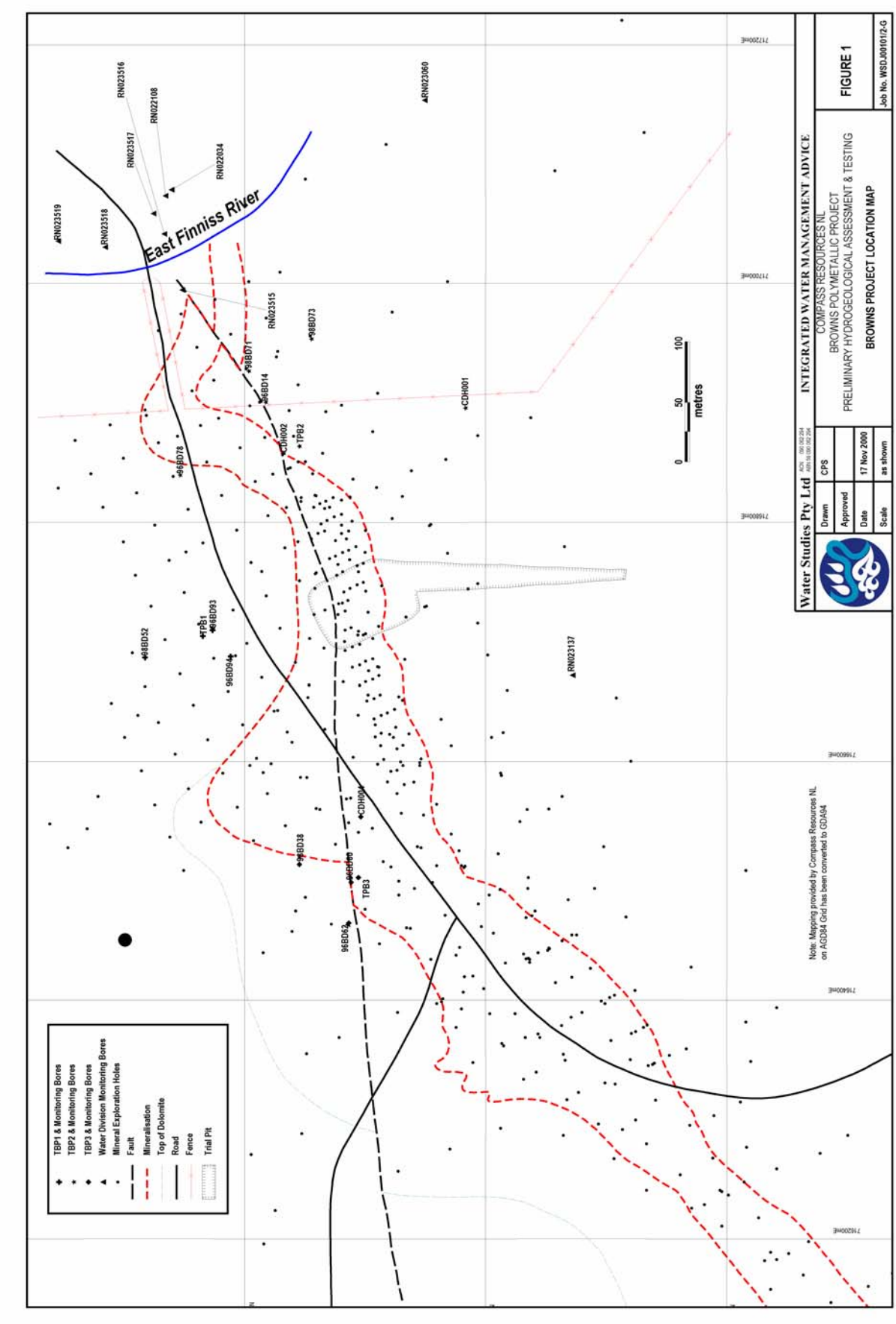



**FIGURE 5.3 Bore Water Hole Locations**

## 5.2 Assays

Assays of ore, process solution and ground water were obtained for dose and environmental impact calculation purposes. The assay results are as follows.

### 5.2.1 Solids

Early analytical work for Compass Resources on the Browns project showed that the $^{238}U$ and $^{232}Th$ decay chain radioactivity in ore and flotation concentrates from the sulphide ore body was in secular equilibrium.

Previous assays [Collier 2000] on Compass samples indicated that $^{232}Th$ decay chain was also present and contributed about one third of the total contained activity present in tailings and concentrates.

Recent assays on ores are given in **Table 5.3** and **Appendix C**. The contribution from radioactivity in the $^{232}Th$ decay chain is not significant – see **Appendix C5**.

### 5.2.2 Liquids

Bore hole water was collected, acidified and evaporated for counting.

Four leach solutions were assayed for uranium, thorium and progeny, as shown in **Tables 5.4** and **Appendix C4** (gamma). There is no evidence for the dissolution of radionuclides other than those of uranium plus some thorium from the $^{238}U$ decay chain. Thorium-232 chain radionuclides were detected but were not significant compared with the uranium decay chain radionuclides, i.e their contribution to the total contained activity was less than 5%.

**TABLE 5.4**

**Uranium and Thorium Content of Acid Leach Solutions – ICP MS (mg/L)**

| Client ID | ANSTO ID | Appearance | U | Th |
|---|---|---|---|---|
| B49 | Comp-300605-1 | pale blue-green | 2.23 | 0.12 |
| B50 | Comp-300605-2 | $FeSO_4$ green | 4.24 | 0.84 |
| B51 | Comp-300605-3 | pale $CuSO_4$ blue | 0.82 | 0.34 |
| B52 | Comp-300605-4 | strong $CuSO_4$ blue | 0.66 | 0.16 |

$^{226}Ra$ is frequently observed in recycled acidic solutions and accumulated process scales, however samples would need to be collected and assayed after prolonged plant operation.

The three borewater samples were assayed by ICP OES (**Appendix C3**) and ICP MS and contained less than 1 μg/L of either uranium or thorium. Gamma analysis (**Appendix C6**) confirmed the very low concentrations (below detection limits) of most radionuclides. There was some $^{226}Ra$ present.

Uranium is commonly observed in nickel/cobalt precipitates from SX circuits and measures are currently being examined by some producers to separate the uranium from the base metal processing circuits, but this is not proposed for the Browns project.

### 5.3 Deportment of Radioactivity

It is expected from experience, and has been verified by analysis of process streams, that uranium dissolves in the process leach stage. This will accumulate in recycled process water or be removed with neutralisation waste during treatment of a process water bleed stream to minimise end product contamination and any OH & S issues.

$^{210}$Po can be present in acid process liquors and report to intermediate (Pb, Co/Ni) and metal products. This cannot be predicted but should be monitored during plant operation. $^{226}$Ra can also be present at low concentrations in the leach solutions and appear at high concentrations in scales on equipment surfaces and/or adsorbed into synthetic materials such as filter cloths and rubber linings. If this occurs, particular care is required in maintenance of equipment, handling the scales and the disposal of the scales and contaminated equipment.

The dissolution and mobilisation of uranium in leaching can potentially result in more ready migration in the environment. This is rarely observed in practice because the uranium quickly forms complexes and precipitates.

## 6. DOSE CALCULATIONS

Doses to the workforce and public were calculated using available stream analyses, conservative conversion factors, and assumptions made for a range of exposure scenarios.

Procedures and work practices, put in place to minimise broader OH & S or environmental impacts, will reduce the exposure to NORM. These measures include:

- limits on allowable dust loadings in work areas;
- personal protective equipment (PPE) requirements, *e.g.* dust masks and clothing;
- dust elimination by ventilation of enclosed work areas and wetting down work areas; and
- cover placement over wastes and/or blending of net acid consuming materials with net acid producing materials.

Because dose, rather than concentrations and quantities of radioactivity, is the important issue in regard to radioactivity, measured values of dose rather than calculated dose values are more relevant to exposure. Calculated doses are very conservative. However, calculated doses do give an indication of potential exposure and are used as an initial estimate in the absence of other data.

There are a number of pathways by which radioactivity may contribute to the exposure of workers, members of the public and the environment. These are by external gamma radiation, inhalation of long-lived radionuclides, inhalation of radon progeny, ingestion of long-lived radionuclides and injection of radionuclides through wounds or accidents. The last two pathways are relatively insignificant, because normal occupational hygiene practices, which would be in place, are sufficient to minimise the potential contributions from these pathways. Examples of these practices include washing of hands before meals and getting cuts washed and bandaged.

The following assumptions [ICRP, IAEA] are made in regard to exposure to radioactivity:

- Worker or member of public;
- Breathing rate *e.g.* 1.2 $m^3$/h (standard man breathing rate for worker);
- Occupancy e.g. a worker spends 2000 hours per year within a designated area; and
- AMAD of 1 μm. Where dust particle size is not quantifiable, it is assumed to have an Activity Median Aerodynamic Diameter of 1 μm, which is used for environmental and member of the public exposure. It is the default in the absence of actual data, as it is conservative and will give rise to an overestimation of the dose. For dust from a known source, *e.g.* Browns ore, an AMAD of 5 μm is assumed. It is also assumed that the dust is in the worst solubility category for each radionuclide, when selecting the dose conversion factors.

Potential exposure routes (pathways) were considered and either dismissed or calculated for various exposure scenarios, including workers dealing with large quantities of ore, tailings or process liquors. Dose calculations were done for ore handling and transport, for tailings operation and for water treatment and spillage.

Gamma exposure is only significant, if most of the worker's time is spent in close proximity to large quantities of either ore or tailings. This is because the gamma radiation from the uranium decay series is almost exclusively due to the decay products of $^{226}$Ra. The $^{226}$Ra is present in both the ore (in equilibrium with the uranium) and the tailings, and, potentially, in process solution scales. Similarly, radon is a decay product of $^{226}$Ra and it will only be present when ore and tailings contain $^{226}$Ra. In addition, exhaled radon (and its progeny) is generally only a concern in enclosed spaces, as it is a gas and soon dissipates in an open area. Worker groups handling these materials are considered specifically in this study.

To estimate the radiological implications of the processing of Browns ore, it is necessary to examine these pathways for the most exposed individuals at each of the major locations, or for major work groups. Where data is not readily available, conservatively high estimates have been used to ensure that the radiological consequences are not underestimated. This means that the overall estimate of radiological dose will be on the high side, but increases the confidence that all doses are well within applicable dose limits.

Background doses should be obtained before commencement of mining activities. These should include external gamma, radon/progeny and green tissue (local plant crop) measurements.

### 6.1 Dose Calculation Methodologies

The gamma dose can be estimated in two ways; by theoretical modelling or by comparison with existing scenarios. Theoretical modelling is carried out to estimate the dose above a flat plane containing uranium and thorium decay chain activity. The calculated gamma dose is based on the concentrations of $U_3O_8$ (including the $^{235}$U decay chain contribution) and $ThO_2$ in the material, and job based occupancy time. Corrections can be incorporated into the dose calculation to allow for the distance between the worker and the ore/tailings, due to the geometry of machinery typically used for handling the material.

Exposure to radon decay products is unlikely to be significant for operations relating to the handling of ores. The exception would be if the material was being handled in bulk quantities within a poorly ventilated area (e.g. if the ore/tailing is stored in an enclosed space). If outside handling is performed or there is good ventilation, then doses from this pathway will be below 0.01 mSv/y for all members of the workforce. However, a worst case approach based on measured data at other sites can be used to estimate maximum potential exposure, as follows.

The average ore grade at Ranger uranium mine in Australia is reported as 0.27% $U_3O_8$ or 0.23 %U [OSS 1991]. The average radon progeny in the Ranger pit (minus background) is 15.6 – 1.9 mWL or 13.7 mWL. This converts to SI units of 13.7 x 2.08 x $10^{-5}$ mJ $m^{-3}$ or 2.85 x $10^{-4}$ mJ $m^{-3}$. The highest measured concentration of uranium in Browns ore is approximately 28 ppm U, which is 82 times lower than the Ranger ore grade. Allowing for this lower concentration, the dose will be equivalent to 2.85 x $10^{-4}$ / 82 or 3.4 x $10^{-6}$ mJ $m^{-3}$. For workers exposed to the Browns ore for 2000 h/year, this equates to 2000 x 3.4 x $10^{-6}$ or 6.8 x $10^{-4}$ mJ $m^{-3}$ per year. Using a radon conversion factor of 1.4 mSv per mJ h $m^{-3}$ [IAEA 1996], the annual dose from radon progeny is 6.8 x $10^{-4}$ x 1.4 or 0.001 mSv per year[2]. This dose is likely to be an overestimate due to the data being within a pit environment; dispersion of radon would be higher in a surface plant environment. The calculation can be adjusted pro-rata for different concentrations and occupancy times.

Exposure due to dust inhalation is calculated by estimating the dust loading in the air, allowing for any protection measures taken, and multiplying by the standard breathing rate and time spent (occupancy) in the area, where there is dust. The dust loading values used are based on a combination of ANSTO experience and direct monitoring of dust loadings in facilities performing similar work. As a rule of thumb:

- 1 mg/$m^3$ suggests no apparent dust, perhaps only a haze;
- at >1 mg/$m^3$, there is a visible dust halo; and
- 100 mg/$m^3$ is very dusty.

The dust loading allows the total amount of dust breathed into the body to be calculated. This is multiplied by the activity of the material to give the activity breathed in. This value is converted to a dose (mSv) by using the dose conversion factors in the BSS 115 [IAEA, 1996] for the appropriate AMAD. Changes in dust loading, additional breathing protection, time spent in the area or changes in material activity will give a proportional change in dose.

A very simple model, using highly conservative assumptions, was used initially to determine whether more detailed information was required, for example, occupancy and the presence of different radioisotope chains. This approach is one commonly recommended, for example, in the International Atomic Energy Agency Safety Guide WS-G-2.3 [IAEA 2000]. The assumptions made and used in the model to calculate the potential dose from the inhalation of dust are provided for each scenario.

[2] Dose from thoron ($^{220}$Rn) and progeny will be less than this.

## 6.2 Pathways to Exposure

### *6.2.1 Dust from mining*

The Browns ore containing, on average, 10-20 and a maximum of 33 ppm $U_3O_8$ and 23 ppm Th is mined, handled and transported. For this dose calculation, the maximums of the ranges of ore analyses have been used to provide a worst case estimate.

The workgroups and key assumptions for the handling of ore are provided in **Table 6.1**. For workers handling large quantities of ore, the exposure to external gamma radiation, inhalation of radionuclides in dust and inhalation of radon/thoron progeny are the exposure pathways, which require consideration.

The workgroups, which have been examined in these scenarios, are given below, along with the assumptions regarding dust loading, breathing protection, material radionuclide concentration, time in close proximity to the material, and occupancy time whilst exposed to dust. When dealing with ore, an AMAD of 5 μm is assumed.

**TABLE 6.1**

**Assumptions and Workgroups for Ore Handling**

| Workgroup | Dust Loading ($mg/m^3$) | Breathing Protection | Material | Proximity Time (h) # | Dust Time (h) * |
|---|---|---|---|---|---|
| Ore Stockpile | 1 | None | Browns ore | 1000 | 1000 |
| Ore Transport | 10 | None | Browns ore | 1000 | 100 |
| Ore Loading & Unloading | 10 | None | Browns ore | 1000 | 500 |
| Public Exposure | 1 | None | Browns ore | 100 | 100 |

# Time spent in close proximity (occupancy) for gamma exposure calculation

* Time spent in close proximity (occupancy) for exposure to dust inhalation calculation

The above ore handling workgroups also have some special case assumptions. The stockpile is assumed to have some restriction on ventilation, and personnel spend half their working time on or around the ore. Transport drivers will only receive exposure during one way of their trip (when the truck is loaded). They will only be exposed to dust when loading or unloading and will sit at a distance of 2 m from the concentrate (quarter of the dose). The loader drivers are at a distance of at least 2 m (quarter of the dose) and no allowance is made for breathing protection or shielding of cabins. The public spend 5% of the time close to trucks and are exposed to concentrate dust for this time.

The estimated exposures from ore handling activities are provided in **Table 6.2**. The dose is calculated to include the $^{238}U$, $^{235}U$ and $^{232}Th$ decay chains and gives a value of less than 1 mSv/year for each scenario.

**TABLE 6.2**

**Estimated Exposures for Ore Handling Workgroups**

| Workgroup | Gamma Dose (mSv/year) | Dust Dose (mSv/year) | Radon Dose (mSv/year) | Ingestion Dose (mSv/year) | Total Dose (mSv/year) |
|---|---|---|---|---|---|
| Ore Stockpile | 0.25 | 0.04 | < 0.01 | Negligible | < 0.30 |
| Ore Transport | 0.06 | 0.04 | < 0.01 | Negligible | < 0.11 |
| Ore Loading & Unloading | 0.06 | 0.20 | < 0.01 | Negligible | < 0.27 |
| Public Exposure | 0.03 | < 0.01 | Negligible | Negligible | < 0.04 |

### *6.2.2 Radon in the open pit and TSF*

Exposure from radon/progeny in the open pit during mining was calculated above and shown to be insignificant.

Assuming that dust loadings, occupancy etc do not exceed those in ore handling, doses from tailings operation will also be below the allowed limit. It is recommended that topsoil monitoring be done during subsequent mine rehabilitation as conditions could change for subsequent land use (higher occupancy).

The estimates of the potential dose, as given in **Table 6.2,** indicate that the maximum potential CED from the inhalation of dusts was 0.2 mSv/y. It will be significantly less than the annual allowable dose limit (from all sources) of 1 mSv/y for members of the general public and, as such, does not require a less conservative model to be used. These results are frequently compared with background doses (to put the values into perspective) measured before mining commenced.

The conclusion from the above calculations is that the indicated doses for various scenarios[3] and all pathways are well below the allowed limit for a member of the general public. As a first indication, the results would suggest that the environmental impact from the Browns project would also be low.

A more direct measurement of the impact of radiation on the environment is currently being developed by the international scientific community, as discussed in **Section 4.4**. Some of the proposed techniques are well advanced and one of these is used in the **Section 7** to evaluate the likely environmental impact of the Browns project. These are used as a next step beyond establishing that the expected doses are less than the limits acceptable to a member of the public and therefore of limited environmental impact.

[3] Some scenarios, e.g. process scale handling and disposal, would still require close attention during operations.

# 7. REVIEW OF RADIOLOGICAL IMPACT ON THE ENVIRONMENT

Base line environmental data, including radiological data, is required prior to the commencement of mining and processing activities at the Browns project site. This is particularly important because of the proximity of the former Rum Jungle workings. There is some potential for the project to inherit a radiological legacy because of its location, although this might be a "perceived" radiological legacy rather than a real one, and the Browns project could contribute to improvement in any existing site radiological issues. There is considerable base line data already available on the environmental impact of the adjacent Rum Jungle Mine [see Kraatz 1998; Markich and Jeffree 2002 and references therein].

Baseline information can be obtained by;

- a site radiological and sampling survey; and
- a review of existing data from previous studies of the area.

Monitoring may be required to observe any bore hole or surface water quality changes with time around the operations, upstream and downstream of the specific project affected site area. Circumstances could change in the areas of the former Rum Jungle mines resulting in higher concentrations of species arising from these areas due to cover deterioration, erosion and severe climatic conditions.

As discussed in **Section 4.4**, current regulatory controls on radiological impact are based on the assumption that the protection of humans will result in the protection of the environment. As a starting point therefore, the indicated doses to humans from radioactivity concentrations, plus assumptions for specific scenarios, give an indication of the likelihood of whether there is potential for a significant impact.

In addition to this, the ICRP has proposed new approaches to developing controls to limit environmental impact of radiation by using reference animals and plants for the estimation of dose and using "derived consideration levels" as the basis for the development of regulatory regimes for the protection of the environment.

## 7.1 Environmental Impact Assessment Tools

Dose estimation software can be combined with dose-response data to provide a basis for quantitative and probabilistic ecological risk assessment relevant to the release of naturally occurring radionuclides into the ecosystem. One technique is described in detail in the literature [Twining 2003] and is based on software and data that:

a) estimates the exposure;

b) provides the response of affected organisms; and

c) estimates the probability of an effect.

In a first-pass approach to Radioecological Risk Assessment (RRA), used here, two exposure scenarios were derived from a combination of available data and ANSTO experience at the Rum Jungle site. Using Radiological Impact Assessment (RIA) software (Copplestone et al. 2001 and updates thereof), potential doses were calculated to a range of wildlife groups, based on reference organisms and concentration factors. Then, in a tier-1 RRA, the maximum dose

to any wildlife group was compared with UNSCEAR guidelines on acceptable radiological exposure levels. It must be noted that the software is based on European ecosystems and organisms and is therefore not specific to conditions found in monsoonal Australia.

## 7.2 Environmental Impact Scenarios

Two worst case scenarios were considered for possible exposure of the environment to naturally occurring radioactivity, from NORM derived from ores and the processing of ores. These are described below. Any measures taken to limit the dispersion of processing materials (and therefore the mobilisation of any contained pollutants), including dust, process water and wastes, for non-radiological related reasons, will further limit the radiological impact.

### *7.2.1 Spillage of ore, tailings and/ or process water.*

(a) Ore is spilt around handling and trucking areas over the mine site. The dose from dust inhalation was calculated in **Section 6.3**.

(b) Tailings could breach retaining barriers, and

(c) Process water will be contained in a minimum footprint area of the operations. Tailings water will contain a minimum quantity of valuable component (Cu, Ni, Co) species, after CCD washing. The process solution may contain accumulated concentrations of contaminant species (including radionuclides), as is the case when raffinate is used in CCD washing, and will have a limited environmental impact, if it is released to the environment. Excess process water will need to be treated before release, if release of such water is approved by the regulator, depending on specific site circumstances.

Two scenarios were considered, as follows:

Scenario 1 – Aquatic, freshwater: a tailings solids spill, covering the bottom of a pool in the East Branch of the Finniss River. This very unlikely event (because of the distance to the River), is assumed to occur in the recessional flow period of the early dry season, *i.e.* when dilution from rain and surface waters is minimal and the period of exposure is likely to be at its maximum.

Scenario 2 – Terrestrial: tailings dust blankets an area of naturally vegetated ground. This is assumed to occur in the early dry season, when the dust is unlikely to be rapidly washed away.

The indication from the assessment of potential dose to wildlife groups including plankton, water plants, invertebrates, amphibians and fish is that, for scenario 1, $^{238}U$ alone could contribute a maximum dose to the most susceptible wildlife group (frogs) of 4,800 microGrays/h. This exceeds the UNSCEAR guidelines (400 microGy/h) and therefore fails a tier-1 RRA. The normal action would be to make further analysis[4] and refine the exposure model, *e.g.* dilution in the environment calculation to assess how far downstream the effect might be felt, and move to a tier-2 probabilistic RRA using AQUARISK.

Similarly, a maximum indicated tailings discharge water concentration, for example, of 2,620 $Bq/m^3$ $^{238}U$ has less potential impact (a maximum dose of 1800 microGy/h), but exceeds the

[4] The data used in the model and concentration factors are applicable to European ecosystems.

guidelines for water plants and frogs, although by much less. Other wildlife groups, receive estimated doses that are less than the UNSCEAR guideline value.

According to the Australian Water Quality Guidelines [ANZECC, ARMCANZ 2000], there are insufficient data to provide specific chemical toxicity guidelines for uranium in freshwater. Charles et al [2005] report relevant chemical EC50 data for uranium in the range 0.04 to 2.0 mg U/L. The estimated uranium concentration in tailings discharge waters of 0.21 to 4.2 mg/L (the latter being the maximum leach solution concentration), indicate that chemical toxicity is also likely to be important. We also note that recent comparative information [Garnier-Laplace 2003] indicates that, for a given chemical concentration of uranium in freshwater, the chemical toxicity is likely to be considerably greater than the radiological toxicity.

### *7.2.2 Dispersion of airborne dust*

Mining operations and transport of ore and waste rock will result in some dispersion of dust. Dust is generated particularly under dry conditions. Nuisance dust is usually minimised in practice by watering roadways. This will also reduce any radiological impact.

In this second, terrestrial scenario, we are assuming that ore or tailings dust blankets an area of naturally vegetated ground at a concentration of 353 Bq $^{238}$U/kg (dry weight – highest uranium grade reported). The Terrestrial RIA software indicates a maximum dose of 26 microGy/h for fungi, compared with an UNSCEAR guideline value of 40 microGy/h. A tree is calculated to receive an overall dose (internal and external) of 5.2 microGy/h. The impact of mining, ore handling and crushing would be less (exposure via dust dispersion) than would the potential impact of waste spillage on aquatic species.

### *7.2.3 Decommissioning*

The objective, as stated in the Notice of Intent [Compass 2004], is “to achieve safe and stable landforms that do not cause unacceptable downstream water quality” after (and during) mining. Site rehabilitation will be progressive during operations. All proposed work will be carried out in agreement with the stakeholders (government, local community, NLC/Traditional Owners). It will include re-spreading of stockpiled topsoil. Topsoil cover will also have an important impact in reducing any radiological impact.

The end-use of reclaimed land may be determined by the dose arising from radioactivity contained in deposited tailings and may require considerable and expensive cover placement, when concentrations are high. This is not expected to be an issue for the Browns project, however, any cover placement is usually achieved more economically during the mine life, in comparison to after close-down of the site, and by establishing licensing conditions with the authorities based on good data on the nature of the contained radioactivity. Any potential for increased radionuclide mobility, for example, due to dust, milling of ore and chemical processing, is best addressed during operations.

The open pit will remain, but will be rehabilitated as a final void. Waste rock and tailings areas will be rehabilitated as raised areas with appropriate contour development to minimise adverse erosion by surface water.

As part of the Mine Management Plan, Compass may need to have measurements made, at various points in its operations, by an independent accredited health physicist. This will include, for example, the measurement of dose, through inhalation, around dusty work areas and the measurement of radon exhalation rates above waste areas. Measurements of dose at such locations would be carried out to demonstrate that Compass can be exempt from or subject to minimal regulatory requirements.

The presence of NORM in ore can give rise to radioactive wastes, such as scales, which can have an environmental impact if disposed of inappropriately. Such scales usually contain radium and their formation is dependent on the specific processes and equipment used. The exact composition of such scales is difficult to predict.

### 7.3 Background Data

Considerable background data (since early studies [Davey 1975]), on the former Rum Jungle vicinity, is available in assessing the environmental impact of the proposed Browns project on the region. Much of the recent work involves the impact of toxic elements on off-site, downstream environments, because it was recognised, at an early point in the studies, that the radiological impact was not significant in comparison with the impact of toxic base metals, principally copper.

## 8. CONCLUSIONS

The concentration of naturally occurring radioactivity in the Browns deposit is very low and the expected impact on the environment will be low. General good practice in dust control and waste management, required in any mining operation, will limit the already small anticipated impact. Some specific conclusions from the radiological impact study include the following:

- The use of available modelling tools for dose calculation indicates that the impact of the Browns project on the environment will be minimal, if worst case scenario situations are prevented through good management practices. There is, however, a potential environmental impact in the local aquatic ecosystem under worst case scenario conditions at certain times in the seasonal cycle, but no assessment has been made of how far downstream the effect could go;
- The Browns ore and tailings are not radioactive from a regulatory viewpoint (no radionuclide is present at a concentration > 1 Bq/g) and their handling would not give rise to exposure to the workforce, public or the environment exceeding the 1 mSv/y dose limit;
- Radiological dose to members of the general public via external gamma and inhalation of dust: The maximum potential dose of 0.4 mSv/y for an adult is less than the annual dose limit of 1 mSv/y for members of the general public; and
- Treatment of the ore results in disruption of the uranium decay chain, which can have operational and radiological implications, as uranium dissolves and deports according to

specific plant conditions. There is also a potential radiological risk from scales formed in processes.

Continued collation of data on the characterisation of the naturally occurring radioactivity in its ores and residues (how it occurs, where in occurs, can it be removed or reduced) will assist Compass to assist potential risks arising from;

- increasing regulatory scrutiny;
- the marketability of its products; and
- public (perception) concern that may arise, including from the potential environmental impact.

Compass will minimise any significant hazard by adopting best practice in mine management to address relevant issues such as:

- minimising the operation's footprint and therefore the impact;
- keeping aware of changing regulations pertaining to environmental impact and thereby being prepared to accommodate these changes and reduce the risk. Although current and proposed regulations are based on the best scientific knowledge at the time, there could possibly be tighter scrutiny of environmental limits in the longer term as a result of current ICRP deliberations; and
- applying modern OH & S, environment and ALARA policies.

## 9. RECOMMENDATIONS

It is recommended that the following be done in regard to the management of the potential radiological impact of the Browns project:

1. Background radioactivity data for the site should continue to be collected before mining commences. This includes site measurements of external gamma (use existing airborne data as a guide), air (dust and Rn), water quality testing and green tissue analysis. The data provided from green tissue analyses must be sufficient to determine if there is any change in radioactivity concentrations in local crops. Further review of existing literature available for the area is suggested. Some of this data is referred to in the Browns project NOI bibliography.
2. A site radiological survey should be carried out once the plant has been in continuous operation for a year, *e.g.* radon and dust in the pit and around the tailings placement areas. Subsequent surveys will depend on the outcomes from this survey. Sources of elevated radioactivity, such as accumulated NORM, should be identified and the potential for worker exposure during maintenance should be scrutinised.
3. Borehole and surface run-off water quality should continue to be monitored (prior to and during mining), as the project develops, to assess:
   - the impact of the Browns project; and

- the contribution from any deterioration of the cover condition on the former Rum Jungle workings areas, outside the Browns project area.

4. Other sources of ore, not in the mineral leases, *e.g.* Area 55 and Mt Fitch, may need to be assessed, but would be subject to separate independent permitting.

The doses from operations at the Browns project are expected to be low, and below those currently considered to be of regulatory concern. However, there is potential for a greater impact on the environment if:

- radioactivity accumulates in the processes, such as in radium scales or uranium in precipitates, and is not managed appropriately; and
- direct measures of the impact on biological species are adopted into regulations in future and some species are identified as threatened under worst case scenarios.

Practical and realistic measures, considered within the bounds of good practice, will prevent any unacceptable impact of the Browns project.

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## 11. REFERENCES

ANSTO [2001] The Finniss River – A natural laboratory of mining impacts, past, present and future, Symposium, Darwin, 23-24 August.

ANSTO [2005] Analysis of Compass samples, Technical note 05/08, March.

ANZECC, ARMCANZ [2000] Australian Water Quality Guidelines for Fresh and Marine Waters, Australian and New Zealand Environment and Conservation Council and Agriculture and Resource Management Council of Australia and New Zealand, Canberra.

ARPANSA [1999] Regulations - web

ARPANSA [2001] Safe transport of radioactive material, Radiation Protection Series N$^{o.}$ 2, Code of Practice, July.

ARPANSA [2004] National directory for radiation protection, Edition 1, Draft, March.

ARPANSA [2005] Code of Practice and Safety Guide for Radiation Protection and Radioactive Waste Management in Mining and Mineral Processing, Draft.

Charles et al [2005] Chemosphere.

Collier D.E., Comarmond M.J. and Brown S.A. [2000] Deportment of radionuclides and acid base accounting in the Browns process, ANSTO commercial in confidence report, November.

Compass Resources NL [2004] Browns oxide project, Notice of Intent, 1 December.

Compass Resources NL [2004] Annual report.

Copplestone D., Bielby S., Jones S.R., Patton D., Daniel P. and Gize I. [2001] Impact assessment of ionising radiation on wildlife, R&D Publication 128 (updated July 2002), Environment Agency, Bristol, UK, 222 pp.

Davey D.R. [1975] Rum Jungle environmental studies, Australian Atomic Energy Commission Research Establishment, Lucas Heights.

Garnier-Laplace J., Fortin C., Adam C., Simon O. and Denison F.H. [2003] Chronic radionuclide low dose exposure for non-human biota: challenges in establishing links between speciation in the exposure sources, bioaccumulation and biological effects – Uranium in aquatic ecosystems: a case study, 15-24, In IAEA, 2003, Protection of the environment from ionising radiation, Proceedings of the third international symposium on the protection of the environment from ionising radiation, Darwin, Australia, July 2002 (unedited papers, IAEA-CSP-17), International Atomic Energy Agency, Vienna, Austria.

IAEA [2000] Regulations for the Safe Transport of Radioactive Material, Safety Standards Series N$^{o.}$TS-R-1, 1996 Edition (ST-1, Revised) International Atomic Energy Agency, Vienna.

IAEA [2000] Regulatory control of radioactive discharges to the environment, Safety Guide WS-G-2.3, International Atomic Energy Agency, Vienna.

IAEA [2003] Extent of environmental contamination by naturally occurring radioactive material (NORM) and technological options for mitigation, Technical Report 419, International Atomic Energy Agency, Vienna.

IAEA [2004] Application of the concepts of exclusion, exemption and clearance, Safety Standards Series Safety Guide N$^{o.}$RS-G-1.7, International Atomic Energy Agency, Vienna.

IAEA [1996] International basic safety standards for protection against ionising radiation and for the safety of radiation sources, Safety Series N$^{o.}$115, International Atomic Energy Agency, Vienna.

ICRP [1990-91] Recommendations of the ICRP, ICRP Publication 60, Ann. ICRP 21 (1-3).

ICRP [2003] The evolution of the system of radiological protection: the justification for new ICRP recommendations, J. Radiol. Prot. 23, 129-142.

ICRP [2005] Draft discussion document, The concepts of use and reference animals and plants for the purposes of environmental protection, Annals of the ICRP, ICRP website.

Johnston A. [2005] Development of a regulatory regime for protection of the environment from the effects of ionising radiation, National Conference on Radiation Protection and

Radioactive Waste Management in Mining and Mineral processing, ARPANSA, Melbourne, 11 – 13 April.

NHMRC [1982] Code of Practice on the Management of Radioactive Waste from the Mining and Milling of Radioactive Ores.

NHMRC [1987] Code of Practice on Radiation Protection in the Mining and Milling of Radioactive Ores.

NHMRC [1990] Intervention in emergency situations involving radiation exposure, National Health and Medical Research Council.

Northern Territory [1999] Radiation (Safety Control) Act, Department of Health and Community Services website, 15 September.

Northern Territory [1994] Environmental Assessment Act, Department of Infrastucture Planning and Environment website, 30 December.

Northern Territory [2002] Mining Management Act 2001, Department of Business Industry and Resource Development website, 1 January.

Northern Territory [2002] Radioactive ores and concentrates (Packaging and Transport) Act, Department of Employment Education and Training website, 7 June.

Northern Territory [2004] Mining Act 2001, Department of Business Industry and Resource Development website, 15 March.

Twining J.R., Ferris J.M., Zinger I. & Copplestone D. [2003] A radiological case study of quantitative, probabilistic ecological risk assessment, using recently developed assessment tools, Protection of the Environment from the Effects of Ionising Radiation, Internat. Conf., Stockholm, Sweden, IAEA-CN-109.

UNSCEAR (2000) - United Nations Scientific Committee on the Effects of Atomic Radiation UNSCEAR, 2000 Report to the General Assembly, with scientific annexes. Volume I: SOURCES, Annex B: Exposures from natural radiation sources, United Nations Publications, New York.

## APPENDICES

A. Proposal to Compass Resources NL

B. Samples

C. Analyses

- C1 XRF assays on ore drill core (UNIQUANT)
- C2 NAA thorium assays on ore drill core
- C3 ICP OES assays on bore waters
- C4 Gamma on leach solutions
- C5 Total contained activity in ore

C6 Gamma spectrometry analyses of TBP water samples

D. Decay chains

E. Contacts for regulatory advice

# APPENDIX A

# PROPOSAL TO COMPASS RESOURCES NL

# Proposal to Compass Resources NL

## THE RADIOLOGICAL IMPACT OF THE BROWNS OXIDE PROJECT IN THE NORTHERN TERRITORY

## 1. INTRODUCTION

A short report is required by Compass Resources on ways of addressing issues arising from the presence of low concentrations of naturally occurring radioactivity in the ore from the Browns Northern Territory mineral leases (1.7 sq km), adjacent to the old Rum Jungle area. A broader "Public Environment Report" is required to be completed by Compass by the end of June 2005.

The presence of naturally occurring radioactivity (NORM) in the ore and ground water supply and its distribution in metallurgical processing will require that appropriate measures be taken to minimise the exposure of the workforce and the public, and to minimise any environmental impact from tailings, waste liquors, airborne emissions etc.

The presence of NORM in ore and/or concentrates commonly can result, for example, in the presence of volatile $^{210}$Po and $^{210}$Pb in dusts associated with thermal/pyrometallurgical processes and the presence of radium radionuclides in scales in water treatment circuits. If this occurs, such dusts and scales would require that appropriate handling, transport and disposal procedures be followed.

The presence of radioactivity in end-products being transported and marketed overseas is also becoming of increasing importance as the result of increasingly stringent exemption concentrations specified by the regulators / licensing authorities. These exemption concentrations are the basis for products exported from Australia being defined as radioactive.

Although the concentrations of $^{232}$Th and $^{238}$U decay chain radioactivity are low in the Browns ore, as a starting point to address the above issues, Compass Resources has already analysed for NORM in process intermediates and end products. This analytical work for Compass is contained in ANSTO reports and technical notes.

## 2. Scope of Work

The scope of work is to prepare a short report on "The radiological impact of the Browns project" to support the "Public Environment Report". This work would support the approvals process to mine only the top 20 m of oxide ore and to process this ore by mineral processing and hydrometallurgy to copper metal or sulphate and a mixed Co/Ni intermediate.

## 3. Work Program

The following tasks are required to achieve the objective:

- review existing Compass and ANSTO analytical data on radioactivity in Browns project samples (one half day);
- discussions with Compass re proposed project – including the technology employed and flowsheet (one day);
- estimate radionuclide deportment in process and to end-products (one day);

- a review of radiological impact – environmental (i.e., surrounding ecosystem), occupational and public radiological doses associated with the mining and production of ore at Browns project,(one day);
- dose calculations (one half day);
- internal peer review of draft report (one day); and
- final report with recommendations for management measures arising from the presence of NORM (if required). This would be subject to discussion with the client (2 days).

The review of the potential radiological consequences associated with the processing of the Browns ore covering, mineral processing, hydrometallurgy, smelting and precious metal recovery aspects will include consideration of both realistic and credible worst case exposure scenarios and will rely on information provided by the client. Advice will be provided on potential commercial concerns (product quality) as required by the client.

Some samples of Browns ore, flotation concentrate etc have been assayed for radioactivity but further samples may require analysis. These may include:

- further ores samples;
- site bore waters;
- tailings / leach residues; and
- acidic leach solutions. This will be the only downstream product available within the time frame of this work.

The analytical techniques used will include delayed neutron counting (DNA for uranium), neutron activation analysis (NAA for thorium) and gamma spectrometry.

Analysis of samples will be charged at the following rates, based on receiving pulverised samples:

- delayed neutron counting (DNA for uranium) $25-00 per sample, 20 g required;
- neutron activation analysis (NAA for thorium) $40-00 per sample, 20 g required; and
- gamma spectrometry $250-00 per sample, 100 g solids or 500 mL solution required.

An international and Northern Territory background to regulatory issues associated with the management of NORM in regard to environmental impact will be provided.

Doug Collier
ANSTO Minerals

# APPENDIX B

# SAMPLES

**TABLE B1**

**Ore Samples**

| Sample Description | Weight | Ansto No | Colour | Drying | Pulverise | DNA | XRF | NAA |
|---|---|---|---|---|---|---|---|---|
| | Approx | | | | | x 2 (20g) | (20g) | (20g) |
| From Hole BD02 | | | | | | | | |
| 59492 | >200g | Comp-250505-1 | Mustard | Y | Y | Y | Y | Y |
| 59498 | >200g | Comp-250505-2 | Brown | Y | Y | Y | Y | Y |
| From Hole BD05 | | | | | | | | |
| 59546 | >200g | Comp-250505-3 | Dark Grey | Y | Y | Y | Y | Y |
| 59552 | >200g | Comp-250505-4 | Grey | Y | Y | Y | Y | Y |
| From Hole BD06 | | | | | | | | |
| 59573 | >200g | Comp-250505-5 | Dark Grey | Y | Y | Y | Y | Y |
| 59579 | >200g | Comp-250505-6 | Grey | Y | Y | Y | Y | Y |
| From Hole BD07 | | | | | | | | |
| 59584 | >200g | Comp-250505-7 | Light Grey | Y | Y | Y | Y | Y |
| 59589 | >200g | Comp-250505-8 | Grey | Y | Y | Y | Y | Y |
| From Hole BD08 | | | | | | | | |
| 59607 | >200g | Comp-250505-9 | Red | Y | Y | Y | Y | Y |
| 59611 | >200g | Comp-250505-10 | Yellow/Orange | Y | Y | Y | Y | Y |

| | | |
|---|---|---|
| Sample preparation | 1 | Dry each sample to constant weight at low temperature (approx. 40$^{o}$C) under air. |
| | 2 | Pulverise using conventional ring mill |
| | 3 | Riffle sample for assay - XRF Uniquant |
| | 4 | DNA assay in duplicate |

**TABLE B2**

**LEACH SOLUTION SAMPLES**

| Sample Description | Volume (mL) | Ansto N$^{o.}$ | Free Acidity (g/L $H_2SO_4$) | Ferrous (mg/L) | ICP MS (U and Th) | Gamma |
|---|---|---|---|---|---|---|
| Leach liquor B49 | 150 | COMP-300605-1 | 10.6 | 19.7 | Y | Y |
| Leach liquor B50 | 150 | COMP-300605-2 | 39.7 | 24.6 | Y | Y |
| Leach liquor B51 | 150 | COMP-300605-3 | 17.1 | 1707 | Y | Y |
| Leach liquor B52 | 150 | COMP-300605-4 | 2.8 | 694 | Y | Y |

**Table B3**

**Bore Water Samples**

| Sample Description | Volume (L) | Ansto N$^{o.}$ | | ICP MS (U and Th) | Gamma |
|---|---|---|---|---|---|
| From Hole TPB1 | 5 | COMP-040705-1 | | Y | Y |
| From Hole TPB2 | 5 | COMP-040705-2 | | Y | Y |
| From Hole TPB3 | 5 | COMP-040705-3 | | Y | Y |

All samples have been stabilised with 3% nitric acid but not filtered

# APPENDIX C

# ANALYTICAL RESULTS

## APPENDIX C1

## XRF assays (wt%) on ore drill core (UNIQUANT)

| Sample description | F | Mg | Al | Si | P | S | K | Ca | Ti | V |
|---|---|---|---|---|---|---|---|---|---|---|
| COMP-250505-1 | 0.43 | 12.5 | 0.18 | 28.3 | 0.21 | <0.01 | <0.01 | 0.02 | 0.11 | <0.01 |
| COMP-250505-2 | <0.01 | 6.57 | 2.09 | 16.6 | 0.72 | <0.01 | <0.01 | 1.34 | 0.24 | 0.010 |
| COMP-250505-3 | 0.41 | 0.60 | 9.43 | 27.0 | 0.03 | 0.084 | 3.38 | 0.02 | 0.59 | 0.029 |
| COMP-250505-4 | 0.4 | 0.56 | 10.1 | 25.4 | 0.02 | 0.258 | 3.63 | 0.02 | 0.48 | 0.035 |
| COMP-250505-5 | 0.74 | 0.82 | 9.43 | 26.8 | 0.02 | <0.01 | 4.48 | 0.03 | 0.62 | 0.035 |
| COMP-250505-6 | 0.55 | 0.68 | 9.99 | 21.7 | 0.13 | 0.26 | 3.94 | 0.10 | 2.72 | 0.037 |
| COMP-250505-7 | 1.29 | 0.58 | 8.37 | 27.2 | 0.02 | <0.01 | 4.09 | 0.02 | 0.51 | 0.032 |
| COMP-250505-8 | <0.01 | 0.54 | 8.74 | 24.1 | 0.06 | 0.012 | 3.52 | 0.03 | 0.43 | 0.027 |
| COMP-250505-9 | <0.01 | 0.22 | 5.37 | 28.9 | 0.12 | 0.056 | 0.96 | 0.05 | 0.63 | 0.015 |
| COMP-250505-10 | <0.01 | 0.13 | 0.41 | 12.1 | 0.34 | 0.042 | <0.01 | 0.03 | 0.06 | <0.01 |
| | Cr | Mn | Fe | Co | Ni | Cu | Zn | As | Zr | Pb |
| COMP-250505-1 | 0.007 | 0.93 | 5.84 | 0.038 | 0.029 | 0.99 | 0.011 | <0.01 | 0.0077 | 0.72 |
| COMP-250505-2 | 0.008 | 2.31 | 23.2 | 0.19 | 0.29 | 1.63 | 0.10 | <0.01 | 0.011 | 0.71 |
| COMP-250505-3 | 0.017 | 0.027 | 1.94 | 0.25 | 0.16 | 1.0 | 0.081 | <0.01 | 0.024 | 1.43 |
| COMP-250505-4 | 0.016 | 0.029 | 3.89 | 0.17 | 0.020 | 0.23 | 0.019 | <0.01 | 0.023 | 0.99 |
| COMP-250505-5 | 0.023 | <0.01 | 1.79 | 0.14 | 0.12 | 2.12 | <0.01 | <0.01 | 0.059 | 0.24 |
| COMP-250505-6 | 0.028 | <0.01 | 5.19 | 0.036 | 0.039 | 1.49 | <0.01 | 0.089 | 0.057 | 0.82 |
| COMP-250505-7 | 0.016 | <0.01 | 2.4 | 0.020 | 0.016 | 1.57 | <0.01 | <0.01 | 0.032 | 0.27 |
| COMP-250505-8 | 0.011 | 0.070 | 7.89 | 0.051 | 0.037 | 1.34 | <0.01 | 0.024 | 0.048 | 0.42 |
| COMP-250505-9 | 0.015 | 0.13 | 7.45 | 0.022 | 0.020 | 0.14 | 0.010 | 0.035 | 0.026 | 0.68 |
| COMP-250505-10 | 0.012 | 0.26 | 36.9 | 0.11 | 0.20 | 1.34 | 0.12 | 0.064 | <0.01 | 3.25 |

## APPENDIX C2

## NAA thorium and iron assays on ore drill core

| Sample description | Th (ppm) | % Fe |
|---|---|---|
| COMP-250505-1 | 0.94 | 6.1 |
| COMP-250505-2 | 2.6 | 23 |
| COMP-250505-3 | 19 | 2.0 |
| COMP-250505-4 | 14 | 3.7 |
| COMP-250505-5 | 23 | 1.8 |
| COMP-250505-6 | 14 | 5.1 |
| COMP-250505-7 | 17 | 2.6 |
| COMP-250505-8 | 18 | 8.1 |
| COMP-250505-9 | 16 | 8.3 |
| COMP-250505-10 | 1.5 | 39 |

## APPENDIX C3

### ICP OES scan assays on bore hole water (mg/L)

| SAMPLE ID | Ag | Al | As | B | Ba | Be | Ca | Cd | Cr | Cu | Fe | K | Mg | Mn | Mo | Na |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COMP-040705-1 | <0.1 | <1 | <0.1 | <0.1 | <0.1 | <0.1 | 6.21 | <0.1 | <0.1 | <0.1 | 2.48 | 1.48 | 17.5 | 0.05 | 0.01 | 3.79 |
| COMP-040705-2 | <0.1 | <1 | <0.1 | <0.1 | <0.1 | <0.1 | 3.98 | <0.1 | <0.1 | <0.1 | 1.96 | 6.54 | 41.1 | 0.14 | 0.03 | 11.4 |
| COMP-040705-3 | <0.1 | <1 | <0.1 | <0.1 | <0.1 | <0.1 | 4.28 | <0.1 | <0.1 | <0.1 | 12.6 | 1.66 | 8.53 | 0.23 | 0.03 | 1.2 |

| | Ni | Pb | S | Sb | Sc | Si | Sr | Th | Ti | Tl | U | V | Zn |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| COMP-040705-1 | <0.1 | <0.1 | 13.9 | <0.1 | <0.1 | 0.39 | <0.1 | <0.1 | <0.1 | <1 | <0.1 | <0.5 | <0.1 |
| COMP-040705-2 | <0.1 | <0.1 | 31.9 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <0.1 | <1 | <0.1 | <0.5 | <0.1 |
| COMP-040705-3 | <0.1 | <0.1 | 3.76 | <0.1 | <0.1 | 7.86 | <0.1 | <0.1 | <0.1 | <1 | <0.1 | <0.5 | <0.1 |

## APPENDIX C4

## Gamma assays on leach solutions

| Sample Description | Ansto N$^{o.}$ | Free Acidity (g/L $H_2SO_4$) | Ferrous (mg/L) | Appearance | U * (mg /L) | U * (Bq /L) | $^{234}$Th (Bq/L) | Th * (mg/L) | Th * (Bq/L) | $^{224}$Ra (Bq/L) | $^{235}$U (Bq/L) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| Leach liquor B49 | COMP-300605-1 | 10.6 | 19.7 | pale blue-green | 2.23 | 27.6 | 14 | 0.12 | 0.44 | 0.8 | 1.7 |
| Leach liquor B50 | COMP-300605-2 | 39.7 | 24.6 | $FeSO_4$ green | 4.24 | 52.4 | 30 | 0.84 | 3.4 | 4.5 | 2.6 |
| Leach liquor B51 | COMP-300605-3 | 17.1 | 1707 | pale $CuSO_4$ blue | 0.82 | 10.1 | 7.5 | 0.34 | 1.25 | 10 | 0.7 |
| Leach liquor B52 | COMP-300605-4 | 2.8 | 694 | strong$CuSO_4$ blue | 0.66 | 8.2 | <4.3 | 0.16 | 0.59 | 6.8 | <0.4 |

* by ICP MS

## APPENDIX C5

## Total Contained Activity in Ore

| TOTAL CONTAINED ACTIVITY | | | | | | |
|---|---|---|---|---|---|---|
| ANSTO ID : | COMPASS-250505-2 | | | | | |
| Client ID : | Drill core BD02-59498 | | | | | |
| Date : | 1-May-05 | | | | | |
| Total Contained Activity : | | | 5.32 | Bq/g | | |
| Range : | | | 4.74 | to | 5.91 | |

| Nuclide | Measured | | | Daughter Activity | | |
|---|---|---|---|---|---|---|
| | By | Activity | Error | (Bq/g) | | |
| | | (Bq/g) | (%) | lower | average | upper |
| U-238 | DNA | 0.291 | 3 | 0.283 | 0.291 | 0.300 |
| Th-234 | gamma | 0.320 | 10 | 0.283 | 0.291 | 0.300 |
| Pa-234m | | | | 0.283 | 0.291 | 0.300 |
| U-234 | | | | 0.283 | 0.291 | 0.300 |
| Th-230 | | | | 0.283 | 0.291 | 0.300 |
| Ra-226 | | | | 0.316 | 0.395 | 0.474 |
| Rn-222 | | | | 0.316 | 0.395 | 0.474 |
| Po-218 | | | | 0.316 | 0.395 | 0.474 |
| Pb-214 | gamma | 0.400 | 10 | 0.360 | 0.400 | 0.440 |
| Bi-214 | gamma | 0.390 | 10 | 0.351 | 0.390 | 0.429 |
| Po-214 | | | | 0.316 | 0.395 | 0.474 |
| Pb-210 | gamma | 0.430 | 10 | 0.387 | 0.430 | 0.473 |
| Bi-210 | | | | 0.387 | 0.430 | 0.473 |
| Po-210 | | | | 0.387 | 0.430 | 0.473 |
| | | | Total | 4.550 | 5.117 | 5.685 |

| Nuclide | Measured | | | Daughter Activity | | |
|---|---|---|---|---|---|---|
| | By | Activity | Error | (Bq/g) | | |
| | | (Bq/g) | (%) | lower | average | upper |
| Th-232 | NAA | 0.0106 | 6 | 0.010 | 0.011 | 0.011 |
| Ra-228 | | | | 0.020 | 0.022 | 0.024 |
| Ac-228 | gamma | 0.022 | 10 | 0.020 | 0.022 | 0.024 |
| Th-228 | | | | 0.020 | 0.022 | 0.024 |
| Ra-224 | | | | 0.020 | 0.022 | 0.024 |
| Rn-220 | | | | 0.020 | 0.022 | 0.024 |
| Po-216 | | | | 0.020 | 0.022 | 0.024 |
| Pb-212 | gamma | 0.022 | 10 | 0.020 | 0.022 | 0.024 |
| Bi-212 | | | | 0.019 | 0.021 | 0.024 |
| Po-212 | | | | 0.012 | 0.014 | 0.015 |
| Tl-208 | gamma | 0.0077 | 10 | 0.007 | 0.008 | 0.008 |
| | | | Total | 0.187 | 0.207 | 0.227 |

## APPENDIX C6

## Gamma Spectrometry Analyses of TBP Water Samples

### Methodology

Samples were analysed as received. Approximately one litre of each sample was treated according to ANSTO method:

ENV-I-041-003 Preparation of Gamma Sources from Water Samples Using Agar Gel.

### Spectrometry

Sample sources were counted using an EG & G ORTEC HPGe Spectrometer system comprising a HPGe detector with a carbon fibre end window housed within an inert lead shield.

Activities quoted are at the date of counting, quoted uncertainties are 1 counting errors and less than (<) values are quoted at the 95% confidence interval. The detector system energy calibration was carried out using a National Institute of Standards and Technology (NIST) traceable $^{154}$Eu/$^{155}$Eu/$^{125}$Sb multi-nuclide standard source and the detector system efficiency calibration was determined using IAEA reference materials including RGU-1, RGTh-1 and RGK-1.

**Results**

**Table 1** shows sample descriptions, count dates and sample volumes. Activity results are shown in **Table 2**.

**TABLE 1**

TBP / COMP040705: Sample descriptions, dates counted and sample volumes

| ANSTO code | Sample Description | Count Date | Volume (L) |
|---|---|---|---|
| I048(2) | COMP040705-1 TBP-1 | 09-Aug-05 | 1.003 |
| I049(2) | COMP040705-2 TBP-2 | 10-Aug-05 | 1.002 |
| I050(2) | COMP040705-3 TBP-3 | 11-Aug-05 | 1.002 |

**TABLE 2**

**TBP / COMP040705: ACTIVITY RESULTS IN BQ/L**

| Isotope | keV | I048(2) (Bq/L) | I049(2) (Bq/L) | I050(2) (Bq/L) |
|---|---|---|---|---|
| Pb-210 | 46.5 | < 0.38 | < 0.46 | < 0.36 |
| Th-234 | 63.29 | < 0.37 | < 0.31 | < 0.32 |
| Pb-212 | 238.63 | < 0.13 | < 0.13 | < 0.10 |
| Pb-214 | 351.92 | < 0.14 | < 0.14 | < 0.19 |
| Tl-208 | 583 | < 0.04 | < 0.04 | < 0.05 |
| Bi-214 | 609.31 | < 0.21 | < 0.21 | < 0.21 |
| Ac-228 | 911 | < 0.15 | < 0.14 | < 0.27 |
| K-40 | 1460.75 | < 1.16 | < 1.52 | < 1.35 |

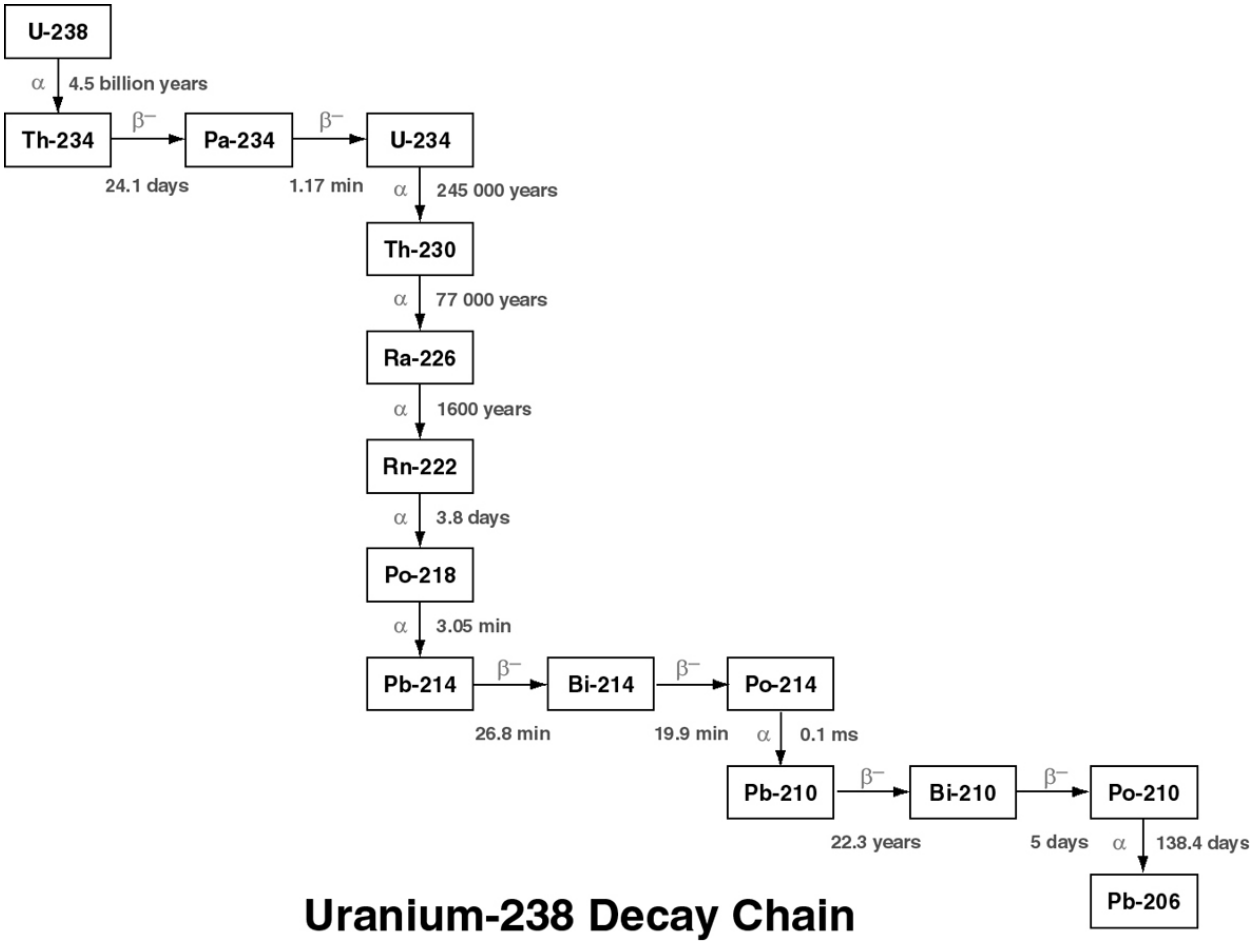
| | | | |
|---|---|---|---|
| **ANSTO ID :** | **COMP-040705-1** | | |
| **Client ID :** | **Borewater TBP-1** | | |
| **Date :** | **17-Aug-05** | | |
| | | | |
| Nuclide | Activity | | Measured |
| | Bq/L | Bq/L | Error (%) |
| Th-234^ | <0.22 | | |
| Pa-234m | <2.8 | | |
| Th-230 | <1.9 | | |
| Pb-214* | <0.056 | | |
| Bi-214* | 0.074 | | 25 |
| Pb-210 | <0.28 | | |
| U-238 | | | |
| Ra-226 | 0.074 | | 25 |
| | | | |
| Ac-228# | <0.076 | | |
| Th-228 | <3.6 | | |
| Ra-224 | <0.24 | | |
| Pb-212# | 0.031 | | 22 |
| Bi-212 | <0.23 | | |
| Tl-208# | <0.020 | | |
| Th-232 | | | |
| | | | |
| U-235 | | | |
| Th-227 | | | |
| | | | |
| K-40 | <0.41 | | |
| ^ Used to determine U-238 activity. | | | |
| * Used to detemine Ra-226 activity. | | | |
| # Used to determine Th-232 activity. | | | |

| | | | |
|---|---|---|---|
| **ANSTO ID :** | **COMP-040705-2** | | |
| **Client ID :** | **Borewater TBP-2** | | |
| **Date :** | **17-Aug-05** | | |
| | | | |
| Nuclide | Activity | | Measured |
| | Bq/L | Bq/L | Error (%) |
| Th-234^ | <0.21 | | |
| Pa-234m | <2.1 | | |
| Th-230 | <0.76 | | |
| Pb-214* | <0.055 | | |
| Bi-214* | <0.042 | | |
| Pb-210 | <0.25 | | |
| U-238 | | | |
| Ra-226 | <0.042 | | |
| | | | |
| Ac-228# | <0.072 | | |
| Th-228 | <3.0 | | |
| Ra-224 | <0.23 | | |
| Pb-212# | <0.023 | | |
| Bi-212 | <0.21 | | |
| Tl-208# | <0.017 | | |
| Th-232 | | | |
| | | | |
| U-235 | | | |
| Th-227 | | | |
| | | | |
| K-40 | <0.40 | | |
| ^ Used to determine U-238 activity. | | | |
| * Used to detemine Ra-226 activity. | | | |
| # Used to determine Th-232 activity. | | | |

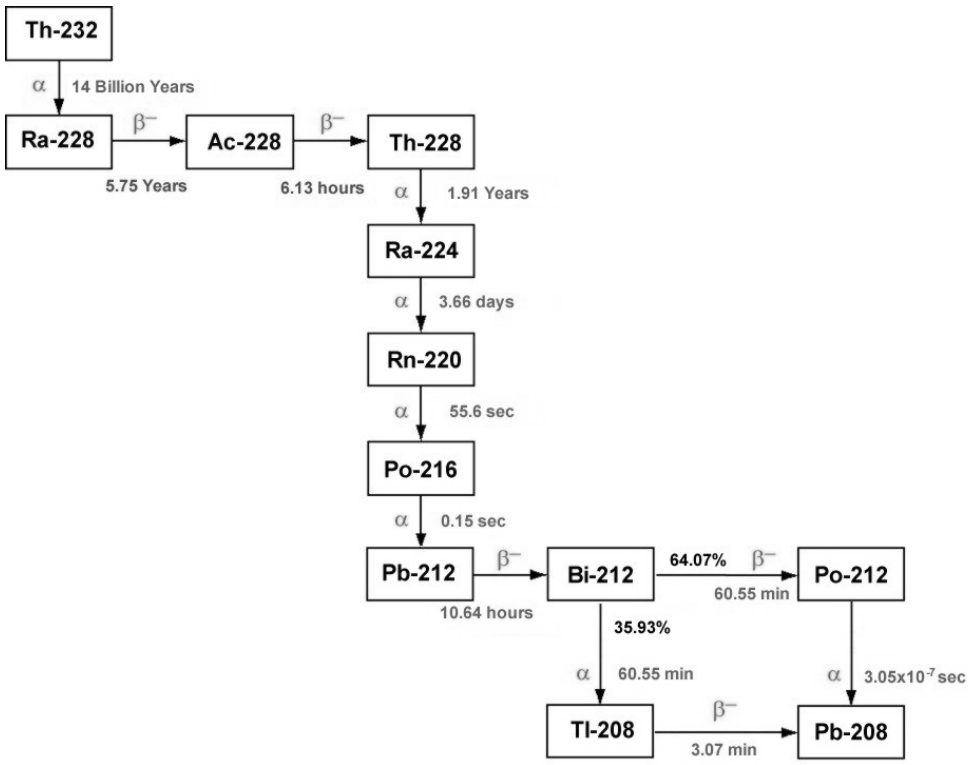
| | | | |
|---|---|---|---|
| **ANSTO ID :** | **COMP-040705-3** | | |
| **Client ID :** | **Borewater TBP-3** | | |
| **Date :** | **17-Aug-05** | | |
| | | | |
| Nuclide | Activity | | Measured |
| | Bq/L | Bq/L | Error (%) |
| Th-234^ | <0.20 | | |
| Pa-234m | <2.6 | | |
| Th-230 | <1.6 | | |
| Pb-214* | 0.090 | | 14 |
| Bi-214* | 0.096 | | 18 |
| Pb-210 | <0.23 | | |
| U-238 | | | |
| Ra-226 | 0.093 | | 32 |
| | | | |
| Ac-228# | <0.060 | | |
| Th-228 | <2.6 | | |
| Ra-224 | <0.21 | | |
| Pb-212# | 0.026 | | 22 |
| Bi-212 | <0.19 | | |
| Tl-208# | <0.015 | | |
| Th-232 | | | |
| | | | |
| U-235 | | | |
| Th-227 | | | |
| | | | |
| K-40 | <0.37 | | |
| ^ Used to determine U-238 activity. | | | |
| * Used to detemine Ra-226 activity. | | | |
| # Used to determine Th-232 activity. | | | |

# APPENDIX D

## URANIUM-238 AND THORIUM-232 DECAY CHAINS




**Uranium-238 Decay Chain**




**Thorium-232 Decay Chain**

# APPENDIX E

## CONTACTS FOR REGULATORY ADVICE

| Juristiction | Department / Location | Group | Contact Name | Telephone Number | Email | Fax |
|---|---|---|---|---|---|---|
| 1. | Department of Health and Community Services<br>Northern Territory | | Russell Robinson | 08 8922 7152 | Russell.Robinson@nt.gov.au | 08 8922 7334 |
| 2. | Dept Business Industry Resource Development<br>Centrepoint 5<br>Northern Territory | Mines and Petroleum Management Division | Richard Jackson | 08 8999 6470 | richard.jackson@nt.gov.au | 08 8999 6527 |
| 3. | Department of the Environment and Heritage<br>Canberra | Environmental Protection and Biodiversity Act | | 6274 1447 | | |