The Effects of Uranium Mining on Health – Case Studies from the Witwatersrand goldfields in South Africa

Mariette Liefferink
The FSE is a federation of community based civil society organisations committed to the realisation of the constitutional right to an environment that is not harmful to health or well-being, and to having the environment sustainably managed and protected for future generations.

Their mission is specifically focussed on addressing the adverse impacts of mining and industrial activities on the lives and livelihoods of vulnerable and disadvantaged communities who live and work near South Africa’s mines and industries.

The FSE is widely recognized as the most prominent of the environmental activist stakeholders in the mining industry -http://www.miningmx.com/pls/cms/mmx_rain.profile_detail?p_nid=372) and its directors amongst the 100 most influential people in Africa’s Mining Industry (MiningMX 2012 & 2013 – “Rainmakers and Potstirrers).
As early as 1987, the US Environmental Protection Agency recognised that “...problems related to mining waste may be rated as second only to global warming and stratospheric ozone depletion in terms of ecological risk.

The release to the environment of mining waste can result in profound, generally irreversible destruction of ecosystems.”

If this is indeed so then the Witwatersrand gold mining area of South Africa is at serious risk.

References:
CSIR. Briefing Note August 2009. Acid Mine Drainage in South Africa. Dr. Pat Manders. Director, Natural Resources and the Environment.
Gold-mining Areas of the Witwatersrand Goldfields

RADIOACTIVITY MONITORING PROGRAMME (01/97-12/97)

MOOI RIVER CATCHMENT (WONDERFONTEIN SPRUIT)

Mooi River Catchment

- Extent of Study Area
- International Boundaries
- Provincial Boundaries

Map showing the radioactivity monitoring programme in the Witwatersrand Goldfields, with a focus on the Mooi River catchment area.
The Witwatersrand has been mined for more than a century.
It is the world’s largest gold and uranium mining basin with the extraction, from more than 120 mines,
of 43 500 tons of gold in one century and 73 000 tons of uranium between 1953 and 1995.
The basin covers an area of 1600 km$^2$, and led to a legacy of some 400 km$^2$ of mine tailings
dams (270 tailings dams and 380 MRDs) containing
6 billion tons of pyrite tailings and 430 000 tons (600 000 t) low-grade uranium.
It is estimated that 6000 km$^2$ of soils are significantly impacted by gold mining on the
Witwatersrand Basin alone (Weiersbye and Witkowski, 2003).

The Witwatersrand Mining Basin is composed of the Far East Basin, Central Rand Basin, Western Basin,
Far Western Basin, KOSH and the Free State gold mines.

A Remote-Sensing and GIS-Based Integrated Approach for Risk Based Prioritization of Gold Tailings Facilities – Witwatersrand, South Africa –
S. Chevrel et al
• The potential volume of Acid Mine Drainage (AMD) for the Witwatersrand Goldfield alone amounts to an estimated 350ML/day (1ML = 1000m³).

• This represents 10% of the potable water supplied daily by Rand Water to municipal authorities for urban distribution in Gauteng province and surrounding areas, at a cost of R3000/ML.

• The gold mining industry in South Africa (principally the Witwatersrand Goldfield) is in decline, but the post-closure decant of AMD is an enormous threat, and this could become worse if remedial activities are delayed or not implemented.

Acid Mine Drainage

• Waste from gold mines constitutes the largest single source of waste and pollution in South Africa (47%).
• Acid Mine Drainage (AMD) is responsible for the most costly environmental and socio-economic impacts. Toxic and radioactive metals occur in AMD.
• Production of AMD may continue for many years after mines are closed and tailings dams decommissioned.
• AMD is not only associated with surface and groundwater pollution, degradation of soil quality, for harming aquatic sediments and fauna, and for allowing toxic and radioactive metals to seep into the environment.
• Long-term exposure to AMD polluted drinking water may lead to increased rates of cancer, decreased cognitive function and appearance of skin lesions.
• Heavy metals in drinking water could compromise the neural development of the fetus which can result in mental retardation.


2002 – 2014
Uncontrolled decant of AMD
Mining Area

Witwatersrand Goldfields:

- Kosh Basin
- Free State Goldfields
- Far West Rand
- West Rand
- Central Rand
- Eastern Rand

Key Issues

- Interconnection of mining compartments
- Acid Rock Drainage and Mine Drainage
- Large Salt Loads
- Decanting of Flooded Mines
- Physical Instability
- Dust Pollution
- Land Use Conflicts with Growing Urban Centres
- Radioactivity (Contamination) and Uranium
When the pH of acid mine drainage is raised past 3, either through contact with fresh water or neutralizing minerals, previously soluble Iron(III) ions precipitate as Iron(III) hydroxide, a yellow-orange solid colloquially known as yellow boy. Other types of iron precipitates are possible, including iron oxides and oxyhydroxides. All these precipitates can discolor water and smother plant and animal life on the streambed, disrupting stream ecosystems. The process also produces additional hydrogen ions, which can further decrease pH.
Robinson Lake

U Levels – 16mg/l (40 000 times higher than background U levels in freshwater)
Tweelopiespruit
Environmental Risks and Hazards Pertaining to AMD and Radioactivity within the Witwatersrand Goldfields

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Neutralised AMD
Precipitated Metals
Unlined West Wits Pit
Far West Rand goldfields

• Tailings Dams contain 100 000 tons of U
• 50 Tons of U discharged annually
• Seepage/Percolation: 24 tons U (1 000 to 1 million higher than the background U concentrations)

Technologically Enhanced Naturally Occurring Radioactive Material

• Point Discharges: 12 tons of U
• Stormwater: 10 tons of U
• Sinkholes: Secondary Sources of U contamination
Sinkholes caused by dewatering and rewatering of aquifers
Air Pollution

42.24 tons of tailings dust per day (West Rand)
Reference: West Rand District Municipality Environmental Management Framework
• Stormwater drainage systems, into which windblown dust from adjacent slimes dams is flushed by run-off from sealed surfaces are also likely to constitute a **major source of potential water pollution**.

• Based on (conservative) assumptions regarding the affected surface area and average deposition rates of dust from adjacent slimes dams, it was estimated that approx. **10 tons of (particle-bound) uranium per year are flushed by stormwater into receiving watercourses**.

• Dust concentrations of up to **3 700 mg per m³** of air were reported from areas adjacent to slimes dams of the East Rand during a windy day.

Challenges pertaining to reclaiming of historical uraniferous tailings dams
The health effects of uranium particles inhaled:

• **Small particles** are carried by the inhaled air stream all the way into the alveoli. Here the particles can remain for periods from **weeks up to years** depending on their solubility.

• Highly insoluble uranium compounds may remain in the alveoli, whereas soluble uranium compounds may dissolve and pass across the alveolar membranes into the bloodstream, where they may exert **systemic toxic effects**.

• In some cases, insoluble particles are absorbed into the body from the alveoli by **phagocytosis into the associated lymph nodes**.

• “**Insoluble**” particles may reside in the lungs for years, causing chronic radiotoxicity to be expressed in the alveoli.

**Tailings Dust Fallout**

• “Radiological Impacts of the Mining Activities to the Public in the Wonderfonteinspruit Catchment Area” that “during the sampling strong dust emissions from slimes dams during wind events were observed.

• Due to the small particle size of the slimes, particulate matter can be transported over relatively long distances to agriculturally used land in his surroundings.

• It has to be mentioned that the deposition of radioactively contaminated dust on leaves of vegetable and forage plants can cause radiation exposures exceeding those from the “inhalation of contaminated dust” substantially, being in the order of dose contribution of the so-called ‘water pathways’”.

Inappropriate Developments

• Direct access to mine sites may also expose the public to risk due to direct external gamma radiation, inhalation and ingestion of radionuclides and chemotoxic metals, as well as the physical dangers inherent to mining sites.

• To limit the risk due to external gamma radiation, the Chamber of Mines uses a guideline that each tailings deposit should have a 500 m buffer zone surrounding it, where no human settlement is allowed. In many cases, however, this guideline has not always been adhered to in the development of new settlements.

KAGISO

Catchment Dams - trespassing problem area

Tailings Storage Facility

Low Cost Housing
Tudor Shaft Informal Settlement
Established by West Rand District Municipality on toxic and radioactive land since 1997

Radioactivity – 15 MilliSieverts per annum
1.6 Million people live in informal settlements close to radioactive mine residue areas. The majority of MRAs are radioactive because the Witwatersrand gold-bearing ores contain almost ten times the amount of uranium than gold.

As a consequence of the uraniferous nature of the ore, Witwatersrand tailings and other mining residues often contain significantly elevated concentrations of uranium and its daughter radionuclides, with the decay series of $^{238}\text{U}$ being dominant.

Brick Manufacturing Works – 20% of the bricks contain uraniferous tailings
Airborne gamma ray survey data have been collected by the Council of Geoscience covering the Central Rand Goldfield.

These data too identify areas of elevated radioactivity. Elevated radioactivity levels were recorded over mining areas, in particular mine residue deposits.

There has also been a historical migration of generally elevated radioactive levels to the urban areas of Johannesburg central business district (CBD) indicating the use of dump and waste material for building purposes as well as downstream plumes in wetlands areas.

• Pollution related to Witwatersrand mines poses a number of hazards to surrounding communities.

• The major primary pathways by which contamination can enter the environment from a mine site are:
  – the airborne pathway, where radon gas and windblown dust disperse outwards from mine sites,
  – the waterborne pathway, either via ground or surface water or due to direct access, where people are contaminated,
  – or externally irradiated after unauthorized entry to a mine site,
  – by living in settlements directly adjacent to mines or in some cases, living in settlements on the contaminated footprints of abandoned mines.

Radioactive (red), MRAs in Gauteng, on sun-shaded SRTM topography. The concentration of radioactive MRAs in the Witwatersrand headwater areas of the Vaal catchment is evident, with some overlap into the Limpopo (Crocodile West) headwaters near Krugersdorp.
Uranium Concentration

Legend
- Rivers
- Urban Areas

Tier 1 risk Quotient - Uranium
- <0.5
- 0.5-2
- 2-5
- 5-10
- >10
- sedriskmapdata Events

Map showing the distribution of uranium concentration with different colors indicating the tier 1 risk quotient.
Arsenic Concentration
Copper Concentration
The measured uranium content of many of the fluvial sediments in the Wonderfonteinspruit, including those off mine properties and therefore outside the boundaries of licensed sites, exceeds the exclusion limit for regulation by the National Nuclear Regulator.

For approximately 50% of the 47 sampling sites, the calculated incremental doses of the respective critical group are above 1 mSv per annum up to 100 mSv pa (548 mSv pa Blyvooruitzicht Mine/Bridge Carletonville)

The radioactive contamination of surface water bodies in the Wonderfonteinspruit catchment area caused by the long-lasting mine water discharges and diffuse emissions of seepage and runoff from slimes dams poses radiological risks to the public resulting from the usage of polluted environmental media;

The pathway sediment→SPM →cattle→milk/meat→person (“SeCa”) can cause radioactive contamination of livestock products (milk, meat) resulting in effective doses of the public in some orders of magnitude above those resulting via the pathway “WaCa.”
Radiological Risks

• Significant radiation exposure can occur in the surroundings of mining legacies, due to:
  • Inhalation of Rn-222 daughter nuclides from radon emissions of desiccated water storage dams (e.g. Tudor dam) and slimes dams.
  • The inhalation of contaminated dust generated by wind erosion from these objects, and
  • The contamination of agricultural crop (pasture, vegetables) by the deposition of radioactive dust particles, which can cause considerable dose contributions via ingestion.

• The comparison between cattle tissue samples from the experimental and control group revealed that nickel, zinc, selenium, lead and uranium concentrations all reveal a practically significant difference.

• The uranium concentration in the cattle samples from the experimental group was 126.75 times higher in the liver, 4350 times higher in the kidney, 47.75 times higher in the spleen, 31.6 times higher in the muscle tissue, 60 times higher in the bone and 129 times higher in the hair than that of the cattle samples from the control group.
Metal Contamination

• “The mean values for the Wonderfonteinspruit samples were found to exceed not only natural background concentrations, but also levels of regulatory concern for cobalt, zinc, arsenic, cadmium and uranium, with uranium and cadmium exhibiting the highest risk coefficients.” (Ref. WRC 1214/1/06)

• “The most important lesson learnt from the studies in the Wonderfonteinspruit is that no short-cuts exist which would allow certain pathways to be ignored in a study of radioactive contamination within these mining areas.” (Ref. DMR RMCS for the East Rand goldfield. 2008)
– Even though a large number of the world’s rivers are contaminated by heavy metals released from present day and historic mining operations, relatively little is known about the effects on communities that live beside and rely on these rivers for food and livelihood. One of the complications is that the toxicity of many metals is a function of such conditions as redox, pH and water hardness.

– Elevated salts and metals can also negatively affect the health of animals in many different ways, depending on the species, age, sensitivity, general health and diet of the consumer, among other factors.

– Some metals, when consumed in excess, can affect organs and the central nervous system, cause reproductive failure or birth defects, and act as cofactors in many other diseases.

– Certain receptors may be more sensitive than others, depending upon species, age, sex, season, body mass, metabolic rate, general health, diet, behaviour, etc, with younger animals and children being generally more at risk than adults under the same conditions of exposure (WHO).

– The potential for trans-generational (genetic) impacts of bioaccumulated metals and NORMs (Naturally Occurring Radiactive Materials) on biota exposed above certain thresh-holds.

– The probability that such latent impacts will only be identified and assessed over the next 100 to 500 years.

• Reference: Anglo Gold Ashanti EIA/EMP West Wits Operations.
Andries Coetzee’s Dam
900mg/kg U

Photo: Courtesy Dr. Henk Coetzee
Tudor Dam - Elevated levels of radioactivity

10 000 – 100 000 Bq/kg

Regulatory Limits: 500Bq/kg
An airborne radiometric survey of the WR and FWR was done for DWAF. Interpretation of the data show many of the residential areas fall within areas of high risk of radioactivity contamination. Ref. DMR. RMCS, 2008.
Randfontein

Wetlands contaminated with radioactive material

Reference: WRC 1214/1/06
At present the U and other heavy metals, such as cadmium, copper, zinc, arsenic and cobalt are adsorbed in the sediment. Plausible environmental conditions such:

- Acid mine drainage

- Acid rain

- Drying out of the sediment and influx of water

- Dredging operations

- Tailings spillages

- Turbulence caused by cattle drinking the water or children playing in the water can cause the mobilization or transport of uranium in the Wonderfonteinspruit.
Uranium Pollution of Water resources in Mined-Out and Active Goldfields of South Africa – A Case Study in the Wonderfonteinspruit Catchment on Extent and Sources of U-Contamination and Associated Health Risks

Prof. Dr. Frank Winde

• “Results indicate that U-levels in water resources of the whole catchment increased markedly since 1997 even though U-loads emitted by some large gold mines in the Far West Rand were reduced. This apparent contradiction is explained by the contribution of highly polluted water decanting from the flooded mine void in the West Rand.

• “800kg of U per year flowing into Boskop Dam as Potchefstroom’s main water reservoir

• “Of particular concern is the fact that U-levels in the WFS are comparable to those detected in the Northern Cape which had been geostatistically linked to abnormal haematological values related to increased incidences of leukaemia observed in residents of the area”.

West Rand goldfields

Sulphate Crusts—1100mg/kg Uranium (highly soluble)
Reference: WRC 1214/1/06
Inlet to Game Reserve
Uranium ppb
Weekly  Oct 2007 – Apr 2010

Domestic Guideline 70 ppb
Directive
Aviary Dam
Weekly Oct 2007 – Apr 2010
Uranium ppb

Domestic Guideline 70 ppb
Directive
Pipeline Spillages of Toxic and Radioactive Water and Slurry
Reclamation
Unrehabilitated Footprints
Unrehabilitated footprints of reclaimed tailings dams
Toxic and radioactive spillages from reclamation operations
Toxic and Radioactive Spillages from Reclamation Activities
Cattle drink from toxic water
Cattle grazing on contaminated soil
Reclamation Challenges (Continued)
Reclamation Challenges (Continued)
Selective extraction of value without ploughing some of the value back into the rehabilitation of the entire mining area
Reclamation Challenges: Spillages and remining of dumps which were not completed
Reclamation Challenges: Pipeline Spillages
Reclamation Challenges: Pipeline spillages
Closure Risks And Liabilities

- Latent impacts may take decades, or even centuries, to manifest themselves.
- Inherent water quality risks
- Gold mine ore bodies – associated with radionuclides
- Hydrological interconnections between mines – cannot be considered in isolation
- Tailings dams and waste rock dumps can never be maintained in completely reducing environment - water risk ad infinitum
- Long term risk re formation of sinkholes
“It is as unacceptable for companies, when they move on, to leave great holes in the earth and polluted rivers as it is to leave disrupted or unenriched communities....” (quoted in Anglo America 2002b:3)
The Externalization of Costs Model

Our national economic growth has been driven by an **externalized cost model** and this can no longer be sustained.

© Adler et al., 2007
Sibanye Gold Limited Uranium Philosophy

SG Statement

It is far more responsible to remove U currently incidental to our Au mining process and to ensure that it is used responsibly than to leave it in the environment as a potential health and pollution risk to our surrounding communities and the environment as a whole.
-SG’s core business is currently gold mining
-The current ore body contains uranium (U)
-Resultantly, SG tailings contains U
-U presents a risk to our natural and social environments
-Regional Closure is the current driving force to SG’s Sustainable Development approach
-Water Use Licensing
-Water Monitoring and management
-Land Use
Acidity of AMD is neutralised with lime causing uranium and other metals to co-precipitate with gypsum which results in the formation of radioactive sludge .... Not SG’s preference. (ION EXCHANGE

Radioactive Gypsum

$\text{CaSO}_4 + \text{M(OH)}_x + \text{U}_3\text{O}_8$
Additional References

• 1960
Final Report, Interdepartmental Committee on Dolomitic Mine Water: Far West Rand. DWAF.

• 1963

• 1995
Screening surveys of Radioactivity in the Mooi River Catchment by the Institute of Water Quality Studies of the DWAF.

• 1996
Scientists predict West Rand Decant in 2002 and suggested a solution in “An Integrated Strategic Water Management Plan for the Gauteng Gold Mines”. The success of the proposed solution is dependent on the mines, water suppliers, water users and Government adopting an integrated approach – with Government taking the lead role. The Western Utility Corporation developed an alleged technical and economical viable solution, but at the time of writing, Government has not given its approval to this initiative. Government alleges that the polluter cannot be allowed to profit from its pollution.

• 1999
Report, “Radioactivity Monitoring Programme in the Mooi River (Wonderfonteinspruit) Catchment”. Institute for Water Quality Studies. DWAF, April. Mining activities are a major contributor to uranium and uranium series radionuclides within the catchment. Concentrations decrease downstream of the sources, indicating removal from the dissolved fraction by interaction with sediments.
2002
Publication of the “Radioactivity study on sediments in a dam on the Wonderfonteinspruit Catchment.” Conducted by the Council for Geoscience and commissioned by the DWAF. Wade et al. (2002) (WRC).

2002
Publication of the “Tier 1 Risk Assessment of Selected Radionuclides in Sediments of the Mooi River Catchment.” WRC Report 1095/1/02 by P. Wade. Radionuclides are concentrated in sediments downstream of their sources. Sequential extractions showed that these radionuclides are distributed in multiple phases within the sediments and that they may be remobilized by environmentally plausible chemical processes such as AMD.

2002
Coetzee et al. (2002) of the Council for Geoscience reported on “Uranium and heavy metals in sediments in a dam on the farm Blauuwbank”. This study confirmed the findings of Wade et al and used further sequential extractions to characterize the sediments in a dam downstream of mining activities in the Carletonville area.

2005
Publication, WRC on “Impacts of gold-mining activities on water availability and quality in the Wonderfonteinspruit Catchment.” Mining-related impacts such as large-scale land degradation associated with DWAttering of karstic aquifers and widespread pollution of surface water and groundwater systems are discussed.

2005
Publication Council for Geoscience, “Contamination of wetlands by Witwatersrand gold mines – processes and the economic potential of gold in wetlands” by H Coetzee et al, Report No. 2005-0106. For more than a century, the mines of the Witwatersrand have discharged contaminated water into the streams and rivers of the area, which led to the formation of a system of large wetlands. Concerns have been raised about their ability to cope with the pollutant loads flowing into wetlands.

2006
2006
Publication of “Impact of the discharge of Treated Mine Water, via the Tweelopies Spruit, on the receiving water body Crocodile River system, Mogale City, Gauteng Province”. DWAF, Report, 16/2/7/C221/C/24. 15.12.2006 by J Fourie et al.

2006

2006
“Archaeological Assessment: The Proposed Wonderfontein Spruit Treated Water Discharge Project.” Matakoma Heritage Consultants. 25 April.

2006

2006

2006

2007
2007

2007

2007
Publication of the “Status Report on the Actions Arising from the Study of Radiological Contamination of the Wonderfonteinspruit Catchment Area (WCA)” 29 October.

2008

2009
Publication of Draft Regional Mine Closure strategies for the West, Far West, Central and Eastern Rand Basins.