Radon Exposure to the Zama-Zamas within Decommissioned Underground Mines (South Africa).

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Introduction

South Africa produced more gold than any other country to date (CMSA, 2014)

About 5900 official abandoned mines (AGSA, 2019)

High Unemployment and Poverty (Southern Africa)


Industrial Scale Illegal Mining: Zama-Zamas (N > 40 000), (SAHRC, 2015)
Figure 1: Map of closed mines across South Africa, the associated population densities (AGSA, 2009), and the positions of three prominent illegal underground mining regions (hotspots). Credit Statistics South Africa.
## Structural Overview

<table>
<thead>
<tr>
<th>Level</th>
<th>Description</th>
<th>Operations</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Illegal miners</td>
<td>Underground workers are performing physical mining and refining operations.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>This group will be the predominant group exposed to underground radon (elevated) compared to the other level 2 to 5.</td>
</tr>
<tr>
<td>2</td>
<td>Local buyers</td>
<td>The group is known to be violent gangs organizing level-one actors and providing them with protection, food, and equipment.</td>
</tr>
<tr>
<td>3</td>
<td>Regional bulk buyers</td>
<td>They are known as regional bulk buyers of precious metals from level-two actors. In most cases, this level has trading permits (SA Precious Metals Act 37 of 2005).</td>
</tr>
<tr>
<td>4</td>
<td>National and international distributors</td>
<td>Combination of national and international distributors using front companies or legitimate traders. In general, they source precious metals from levels one and two.</td>
</tr>
<tr>
<td>5</td>
<td>Top international receivers</td>
<td>Level five is predominantly top international beneficiaries and distributors associated with international refineries.</td>
</tr>
</tbody>
</table>

Table 1: Illegal mining organizational structure in South Africa (CMSA, 2016a; UNICRI, 2016).

Estimate annual value R10 billion (CMSA, 2016a, 2016b)
Working Conditions

Figure 2: (a) Underground goldmine shaft supported with wood beams, source Jannie le Roux. (b) Abandoned mine's supporting shaft, source Jannie le Roux. (c) Zama-zamas travelling towards the mining areas, source Kevin Sutherland. (d) A worker inspecting the ore for traces of gold, source Steven le Roux.

Unventilated Underground Mines
Hazardous Physical Environment
High Exposure Time (T)
Poor Air Quality
Limited Information
Radon Metrology, In-air Assessment Challenges

- Extreme security risks due to gangs, illegal miners and terrorist groups.
- Physical hazards include rockfalls, seismic activity, methane explosions, poor air quality, and floods.
- Difficulty accessing the underground mines.
- Emergency rescue missions are not practical.
- Exposure to potentially high radon levels.

Figure 3: Electronic continuous radon and thoron detector (RAD7, manufactured by DURRIDGE).

Figure 4: Passive track-etched radon detector.
Radon Metrology, In-air Assessment Challenges

Extreme security and physical hazards risks.
Mines are required to monitor NORMs (radon).

Public Records Survey (NNR)

Radon-in-air levels data base for mines which is closed

Law Enforcement and Intelligence Reports

Applicable for ideal occupational conditions

Lower Reference Levels (Baseline)

Dosimetric Parameters

Radon ($^{222}$Rn) activity concentration, $R_n$, [Bq/m$^3$]

Annual Exposure Time, $T$, [hours]
Dosimetry

Epidemiological Approach, Publication 115 (ICRP, 2010) and Publication 134 (ICRP, 2017). The annual occupational effective dose (Ea, mSv) is calculated making use of

\[
E_a = \left( \frac{T \times Rn \times F}{C} \right) \times G
\]

Equation 1

Annual Exposure Time, [T, hours]; Radon Exposure [Rn, Bq/m³]; Equilibrium Factor [F = 0.5]; Determinant per unit exposure, [C, 6.37 \times 10^5]; WLM to mSv conversion factor, [G, 10 mSv per WLM]

<table>
<thead>
<tr>
<th>Region</th>
<th>Collective Average Radon-in-air Activity Concentration, [Bq/m³]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Orkney</td>
<td>300 - 1000</td>
</tr>
<tr>
<td>Carletonville</td>
<td>100 - 800</td>
</tr>
<tr>
<td>Johannesburg</td>
<td>5000</td>
</tr>
<tr>
<td>Vaal River</td>
<td>2000 - 600</td>
</tr>
</tbody>
</table>

Table 2: Radon-in-air levels observed in operational South African underground mines (NNR, 2013).
Figure 5: The estimated annual effective dose ($E_a$) density at various annual occupancy percentages ($T$) and radon levels, making use of an equilibrium ($F$) factor of 0.5. Two regions of interest (ROI) are indicated, $10 \text{ mSv/a} < \text{ROI-1} < 100 \text{ mSv/a}$ and $\text{ROI-2} > 100 \text{ mSv/a}$. 
Conclusion

- Large number of illegal miners ($N > 40,000$) and growing. 5900 official decommissioned mines.
- Unconventional metrology challenges. Innovative solutions required.
- Long exposure times to potentially elevated radon levels ($> 1000 \text{ Bq/m}^3$).
- Annual Exposure of 100 mSv plausible within the Johannesburg and Vaalriver regions.
- No straightforward mitigation solution.
Acknowledgements

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References

Thank you for your attention.