

Assessment of Radiological and Industrial Risks in Sahelian Occupational Settings: Methodological Framework, Indicators and Application to Naturally Occurring Radioactive Material in Chad

Boukar M.^{1*}; Govondandi Lakreo Y.²; Shalom Boukar M.³;
Mbozo'o Mvondo S.⁴; Mangsou Y.²; Goultonga Gapili F.²; Moifo B.⁵

¹University of N'Djamena, Faculty of Exact and Applied Sciences, N'Djamena, Chad

²Radiology Department, National General Referral Hospital, N'Djamena, Chad; Kesmonds International University, Lewes, Delaware, USA

³La Renaissance University Hospital, N'Djamena, Chad; UNICAF University, MSc in Public Health Management

⁴Faculty of Medicine and Biomedical Sciences, University of Garoua, Cameroon

⁵Faculty of Medicine and Biomedical Sciences, University of Ngaoundéré, Cameroon,

Corresponding Author: Boukar M.^{1*}

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Abstract: The rapid industrialisation of Sahelian economies exposes a growing population of workers and residents to physical, chemical and radiological risks that remain poorly documented. This article proposes an integrated methodological framework for assessing and monitoring these risks, built around the assess-prevent-monitor-improve loop and a set of six quantitative indicators linking occupational safety and epidemiology. The framework is applied to naturally occurring radioactive material (NORM) in extractive industries and to indoor radon, using case studies calibrated on Chadian practice: southern oil fields, a cement plant and a fifteen-building radon survey. Results show that simple measurement tools, a shared risk-rating grid and a strictly applied hierarchy of prevention can bring exposures below international reference levels at costs compatible with the budgets of companies in the subregion. A minimal ten-line dashboard for occupational health services in developing countries is proposed.

Keywords: Public Health; Industrial Risks; NORM; Radon; Frequency Rate; Radiation Protection; Chad; Sahel.

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I. INTRODUCTION

An industrial site always exposes two populations: its workers, including subcontractors and day labourers, who are often the most exposed and the least monitored, and its neighbouring communities, which receive the dust, discharges, noise and traffic. Public health treats them together: the same cement kiln causes the operator's silicosis and the village's dust; the same crude oil produces the sampler's benzene exposure and the hamlet's flaring. Global orders of magnitude recall what is at stake: work-

related accidents and diseases kill nearly three million people every year, the vast majority through disease, cancers, pneumoconioses and cardiovascular conditions, rather than through accidents [1].

In Sahelian countries, this double exposure occurs in a particular context: expanding extractive industries, an embryonic occupational medicine, under-resourced inspection services and scarce health data. The available literature focuses massively on industrialised settings; international reference frameworks, notably the publications

of the International Commission on Radiological Protection (ICRP) and the IAEA fundamental safety standards [2, 3], are designed for mature institutions. The research question is therefore the following: how can a country like Chad build, with limited means, an assessment of radiological and industrial risks that is at once quantitative, traceable and directly usable by companies and health authorities?

This article answers in three steps. It first formalises a loop-shaped methodological framework, supported by six indicator equations. It then applies it to the naturally occurring radiological risk, chosen because it is at once invisible, measurable at low cost and representative of the trade-offs of the profession. It finally derives a minimal dashboard transferable to the other sectors, cement plants, breweries and mobile telephony, documented elsewhere in the manual whose methodological component this article synthesises [4].

II. MATERIAL AND METHODS

➤ The Loop framework

The framework chains four functions: assess (identify hazards and rate risks), prevent (apply the hierarchy of prevention: eliminate, protect collectively, organise, protect individually), monitor (measure exposures and health) and improve (lessons learned and action plan). The initial risk rating is written:

$$R = P \cdot G \quad (1)$$

Where R is the risk level, P the probability of occurrence and G the severity, each rated from 1 to 4 on a grid shared between the employer, the physician and the workers' representatives. The grid does not claim metrological truth; it produces a reproducible and defensible prioritisation.

➤ Safety and epidemiology indicators

Monitoring relies on two families of indicators. The first measures workplace events: the frequency rate TF and the severity rate TG, computed per entity, with subcontractors counted separately:

$$TF = \frac{\text{accidents avec arrêt} \times 10^6}{\text{heures travaillées}} \quad (2)$$

$$TG = \frac{\text{jours perdus} \times 10^3}{\text{heures travaillées}} \quad (3)$$

The second family measures disease, whose latency often exceeds a decade: incidence I, relative risk RR and attributable fraction FA:

$$I = \frac{\text{nouveaux cas}}{\text{personnes} \cdot \text{années}} \quad (4)$$

$$RR = \frac{I_{\text{exposes}}}{I_{\text{non exposes}}} \quad (5)$$

$$FA = \frac{RR - 1}{RR} \quad (6)$$

These six quantities suffice for a site dashboard. Their reading is framed by three documented pitfalls: under-reporting, which makes a TF fall without any real progress; the healthy worker effect, which masks an excess risk when selected employees are compared with the general population; and confounding, which attributes to the workstation what belongs to tobacco or housing.

➤ Application to Naturally Occurring Radioactive Material

The radiological component further mobilises the decay law and the ICRP dose quantities [2]. The activity of a source decays as:

$$\lambda = \frac{\ln 2}{T} \quad (7)$$

$$A = A_0 \cdot e^{-\lambda t} \quad (8)$$

And the effective dose E, in sieverts, weights absorbed doses by radiation and tissue factors. Three field studies, documented in the source manual [4] from data calibrated on the orders of magnitude observed in professional practice in the subregion, provide the material: scale deposits in southern oil installations (radium-226 concentrated in production piping), dust exposure at a cement plant with its downwind village, and a radon survey of fifteen administrative and residential buildings, using passive track detectors exposed for two months in the dry season.

The reference levels used are those of international frameworks: 20 mSv per year on average for exposed workers, 1 mSv per year for the public, and 300 Bq/m³ of radon in buildings [2, 3, 5].

III. RESULTS

➤ Rating and the Hierarchy of Prevention Bring Heterogeneous Actors Together

Across the three sites, the P × G grid enabled actors without a common culture (operators, physicians, local authorities) to produce, within a day, a shared prioritisation of ten to fifteen risks per site. Radiological risks never top the initial ratings, which are largely dominated by falls, machinery and heat; they move up as soon as measurement objectifies the exposure, confirming the decisive role of metrology in the perception of invisible risk.

➤ NORM Scale in oil Installations

In production installations, scale deposits concentrate the radium dissolved in formation water. Contact dose rates on scaled pipe sections measured in the case studies range from 2 to 15 µSv/h, against a regional background of about 0.1 to 0.2 µSv/h. Without precautions, a welder working 200 hours per year in contact with sections at 10 µSv/h would receive about 2 mSv per year from external irradiation alone, before any inhalation risk during grinding. The hierarchised control measures applied in the case study,

systematic wetting, cold cutting, zoning and controlled storage of scales, with P3 masks as a last resort, bring the estimated exposure of the workstation below 1 mSv per year.

➤ The Radon Survey

The fifteen-building survey illustrates the typical distribution of radon in a Sahelian climate, where high natural ventilation protects most premises while a few configurations concentrate the risk.

Table 1 Summary of the Radon Survey (Passive Detectors, Two-Month Exposure)

Result class	Number of buildings	Concentration (Bq/m ³)	Action taken
Below 100 Bq/m ³	9	35 to 90	None; new measurement in five years
100 to 300 Bq/m ³	4	120 to 260	Improved ventilation; re-check at one year
Above 300 Bq/m ³	2	380 and 520	Floor sealing, forced ventilation, re-check

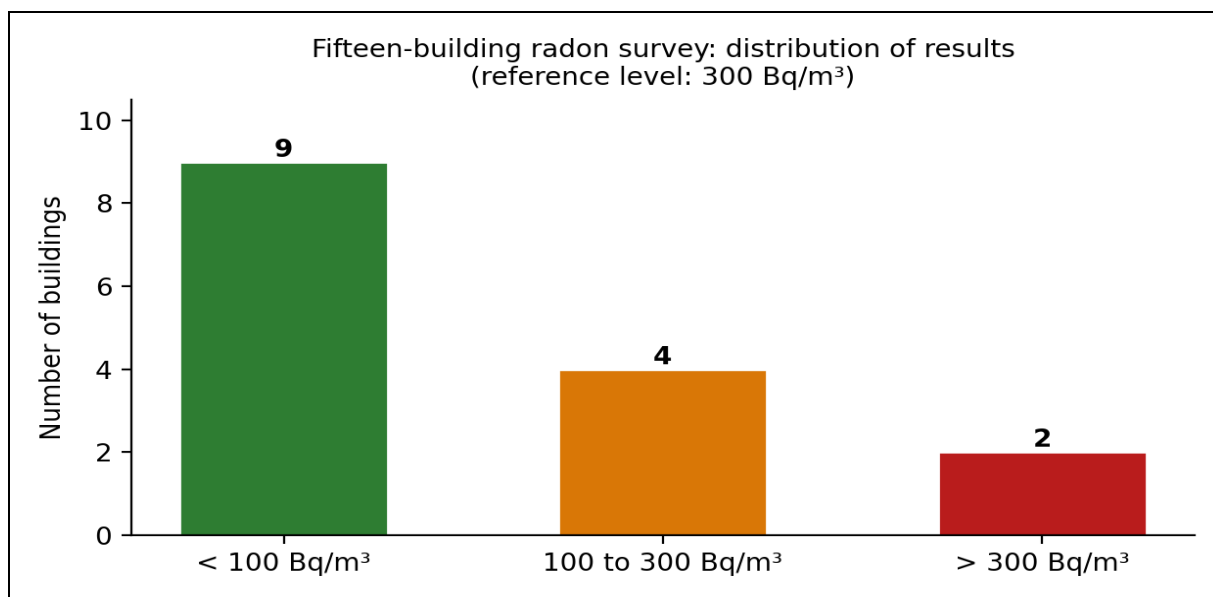


Fig 1 Distribution of Radon Concentrations Measured in the Fifteen Buildings of the Survey, by Result Class.

The two buildings above the reference level share the same characteristics: ground floor on cracked slab-on-grade, openings kept closed for air conditioning, continuous occupancy. After sealing works and restoration of air renewal, re-checked concentrations return below 150 Bq/m³, a reduction of more than 60 %.

➤ The Minimal Dashboard

The convergence of the three sites supports a ten-line dashboard, manageable by a three-person occupational health service: TF and TG per entity, subcontractors separate; number of reported near-misses (whose rise is a sign of a healthy reporting system, not of deterioration); measured exposures to the site's three dominant agents; individual doses of radiation-exposed workers; share of workstations with a risk rating less than three years old; completion rate of the action plan; and two community indicators, residents' complaints and fence-line measurement results.

IV. DISCUSSION

Three lessons emerge. First, scarce means do not preclude rigour: the six indicators of equations 2 to 6 are fed by an hours register, an accident log and a reporting form, and basic radiological metrology (survey meter, passive

detectors) is accessible for a few hundred thousand CFA francs per site. The critical condition is not financial: it is the separation of subcontractors in the statistics, without which the principal's indicators improve while the risk shifts to the most precarious workers.

Second, applying the hierarchy of prevention in order, elimination, collective protection, organisation, personal equipment, is what distinguishes sites that progress from sites that merely equip themselves: personal protective equipment comes only fourth because a helmet has never ventilated a workshop. The radon results confirm it: sealing and ventilation, not any worn equipment, bring concentrations below the reference level.

Third, community monitoring must be built in from the design stage. The cement and oil case studies show that residents' complaints, when recorded and tracked as data, anticipate fence-line exceedances and defuse the perception crises which otherwise are settled in the street or in court.

The limits of this work stem from the nature of its material: case studies calibrated on practice, not epidemiological cohorts, which precludes any estimate of population attributable risk. They define the research agenda: building Chad's first cohorts of extractive and

cement workers, and publishing national radon distributions, which do not exist today.

V. CONCLUSION

A loop-shaped assessment framework, six indicator equations, a shared rating grid and a hierarchy of prevention applied without exception suffice to bring radiological and industrial exposures below international reference levels in the Sahelian context. The operational priority is not the acquisition of sophisticated equipment but the construction of the minimal information system, ten lines per site, that makes risk visible, comparable and governable. Health authorities will find in it the matrix of an applicable regulation; companies, the proof that prevention returns two to three francs for every franc invested.

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