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Study of the post-closure provisions for managing solid tailings from the extraction and processing of uranium ores resulting from the industrial activities of the COMUF company at Mounana, Gabon

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Abstract. Between 1961 and 1999 COMUF extracted about 28 000 metric tons of uranium from the Mounana mining district. This production generated about 7.5 million tons of processing tailings that are stored in areas close to the installations. In the context of the European programme "SYSMIN", the government of the Gabonese Republic commissioned a study to specify the measures to be taken for the restoration of the Mounana mining site and the radiological monitoring to be put in place after the COMUF installations close down. The methodology applied and the restoration and monitoring work undertaken must respect the requirement for an annual added effective dose of less than 1 mSv for persons in the critical population groups.

1. INTRODUCTION

Situated on the Equator, on the Atlantic coast of Africa, GABON covers an area of 267 000 km², with forest occupying about ¾ of the territory. It is populated by 1.2 million inhabitants, i.e. about 4.3 inhabitants per km².

In 1956, a mission from the Commissariat to the French Atomic Energy discovered the first signs of uranium in the region of Mounana, on the Western edge of the Franceville basin in the Province of the High Ogoué in the South East of Gabon.

The Uranium Mining Company of Franceville, COMUF, was created in 1958. Between 1960 and 1999, COMUF extracted 7.5 million metric tons of uranium ore from the Mounana district; the average grade was 0.37 % U.

Extraction of the ore began at the Mounana open pit mine and continued from 1960 to1975. This operation was followed by the mine at Oklo, which operated from 1970 to 1985. Ore was also extracted from underground mines, first at Mounana, then at Oklo from 1977 to 1997 and at Boyindzi from 1980 to 1991.

The extraction of ore ceased in 1999 when COMUF shut down the Mikouloungou open cast mine, which was situated near Franceville, 60 km from Mounana.

From 1960 to 1982, the extracted ore supplied the original milling operations, which had an annual production of 400 to 500 metric tons of uranium. This unit was replaced in 1982 by a new plant with an annual production potential of 1500 tons of uranium.

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COMUF, which had up to 1450 employees including 200 expatriots in 1979, produced 28 000 tons of uranium from 1961 to 1999. COMUF stopped production in July 1999, because the economically extractable reserves were exhausted.

2. ENVIRONMENTAL MANAGEMENT OF THE SITES AFTER CLOSURE OF THE INSTALLATIONS

Processing of the ore extracted from COMUF's underground and open pit mines generated about 7.5 million tons of tailings. Over the years these tailings have been stored behind a dike in the valley of the Gamanboungou River, which crosses the site and also in the Mounana open cast mine and in two talwegs. These storage areas are in the immediate vicinity of the two milling operations that were brought into service in 1961 and 1982.

In 1971, the government of the Gabonese Republic commissioned a study to specify the measures to be taken for the restoration of the Mounana site. This inquiry was based on the framework of the European programme for mining development and diversification (SYSMIN) and also on perspectives for final closure of the COMUF operations. The study concerned not only the risks associated with the presence of radionuclides, but also the means and procedures required for implementation of radiological surveys after closure of the COMUF installations [1].

The study was conducted by the ALGADE Company (France), in close collaboration with the Gabonese Ministry in charge of mines and COMUF's radiation protection and environmental services.

The methodology proposed was based on the principles of justification and optimization of the radiological protection as recommended by the CIPR and the IAEA and repeated in the European directive No. 96/29 of 13 July 1999. The final objective is to achieve an effective annual dose that will exceed the natural regional background level by less than 1 mSv for the critical population groups.

This study which was accepted by the European Union and the relevant Gabonese Ministries, enabled the restoration of the Mounana site to be carried out in the following three stages:

(1) Assessment of the existing radiological environment of the installations before restoration (1997)
(2) Definition and execution of the work on the areas to be decontaminated and restored (1998–2000)
(3) Setting up radiological monitoring after closure (2000–2005)

2.1. Stage 1: Assessment of the radiological environment of the Mounana installations before restoration

This stage enabled:

- Preparing an inventory of all the areas that require restoration,
- Defining the critical groups of the public to be taken into account,
- Assessing the effective annual dose of these critical groups before restoration.

➔ **The inventory of the areas** to be restored was based on a radiological survey that used a portable scintillometer of the SPP2 type equipped with a scintillating crystal of thallium activated sodium iodide associated with a photomultiplier.

The measurements were carried out using a regular 20 m grid, and the scintillometer was carried on the belt, about 1 m from the ground. All the areas with levels higher than 500 counts per second SPP2 ($\approx 0.4\ \mu Gy.h^{-1}$) were listed.

This inventory made it possible to identify a total area of about 75 hectares that will require decontamination. The area included 60 ha of process tailings, the former open pit mine of Mounana, the valley of the Gamaboungou, the area of the confluence with the Mitembe, and the thalwegs South and North.

The critical population groups were chosen in the most realistic manner possible, taking into account the present and future environmental context and the way of life of the local populations. These choices took into account the following criteria:

- population density and its distribution over the areas concerned,
- way of life and eating patterns,
- length of time spent in the different areas concerned.

The critical groups were chosen as being representative of the individuals most exposed to sources that exist at the mining site; the groups must also have a relatively homogeneous exposure to the doses received from these sources [2, 3].

From four types of real exposure scenarios likely to be encountered, two critical groups of the public were identified, as follows:

— Critical group 1 (CG1):

People from the general public who (1) live 5860 hours per year in an environment close to the site, (2) who work 2000 hours per year in the areas of activity on the restored site, (3) who travel 500 hours per year on tracks over the site and (4) who go once a week to their plantation (400 hours a year) near the site,

— Critical group 2 (CG2):

People who (1) live in the close environment of the site (5460 h/year), (2) who work every day in the plantations (2500 h/year) near to the site and (3) those who travel every day over the site (800 h/year).

It is assumed that each person in the group inhales 0.8 m^3 of air per hour, drinks 0.6 m^3 per year of water from the distribution network and consumes 7.5 kg of fish caught downstream from the site plus 190 kg of manioc, which is the basic food of the local population. The manioc is cultivated on plantations close to the site.

It is these two critical groups who are a realistic representation of the public most likely to be exposed and who must, after restoration, receive an effective dose that exceeds the natural background by less than 1 mSv per year.

➔ **The effective dose that exceeds the natural background exposure** of the two critical groups before the restoration work was assessed from measurements supplied by a monitoring network. This network was set up to determine the pathways by which radioactivity is transferred towards the populations (air, water vectors, food chain). In 1997 this network consisted of:

— 10 fixed atmosphere testing stations that provided (1) continuous monitoring of the external exposure rates (thermoluminescent dosimeters), (2) the volumic activities of the short life daughters of radon isotopes 222 and 220 and (3) measurement of the long life alpha emitters (alpha site dosimeters) [4, 5],

— Eleven water-sampling stations that collected samples of all waters discharged from the installations and also from the different receiver watercourses. These samples were analysed monthly for the volumic activities of radium 226 and uranium,

— Three stations for sampling the drinking water of villages situated close to the environment of the mining site. Each month these samples were analysed for the volumic activities of radium 226 and uranium,

— a series of samples taken from the food chain, actually consumed by the populations (fish downstream of the site; manioc and different produce from plantations near the site) for determination of radium and uranium activities.

In order to assess the effective dose due to the sources present on the mining site, i.e. the dose that exceeds the regional natural level, the results provided by the site-monitoring network are compared with a reference station positioned in the village of Omoi. This village is situated away from the site; it is located north of the Mounana region, outside the influence of the site.

The results of the measurements carried out in 1996 and 1997 showed that radionuclide activities found in the water consumed, in the fish caught downstream from the site in the river Lekedi and in produce grown in the close environment were comparable to those found in the natural surroundings, outside the area of influence of the site (fish caught upstream from the site; produce grown in the village of Omoi). Also, the added exposure associated with the ingestion of radionuclides via the food chain is negligible in relation to that associated with external exposure due to gamma radiation and internal exposures due to the inhalation of radon, the radon daughters and the long life alpha emitters.

Table 1 below presents the estimation of the effective added dose for the two critical groups before restoration.

TABLE 1. EFFECTIVE ADDED DOSE FOR THE REFERENCE GROUPS BEFORE RESTORATION

Before restoration	Pathways				Effective*
(01/95 → 04/97)	PAE Rn222 $nJ.m^{-3}$	PAE Rn220 $nJ.m^{-3}$	LLAE $mBq.m^{-3}$	Gamma $nGy.h^{-1}$	Added dose in mSv
Reference group RG1					
Time spent in the environment	130	21	1	160	0.60 +
Work on the industrialized site	183	32	2	820	1.67 +
Travel over the Mounana site	314	31	4	810	0.39 + = **2.9**
Work in the plantations	183	32	1	360	0.15 +
Travel in the Gamaboungou valley	183	32	2	1000	0.10
Reference group RG2					
Time spent in the close environment	130	21	1	160	0.55 +
Work in the plantations	183	32	1	360	0.92 +
Travel in the Gamaboungou valley	183	32	2	1000	0.40 + = **2.3**
Travel over the Mounana quarry	314	31	4	810	0.39
Natural level					
Village of Omoï	56	22	1	140	

* The effective dose is calculated by using the conversion factors given in European directive 96/29 and in the CIPR 65 and 68 to convert the measured level to mSv values.

2.2. Stage 2: Definition and execution of the restoration work (1998–2000)

The restoration work to be undertaken must accomplish the following five objectives:

(1) To guarantee long term safety for the exposed population;
(2) To guarantee that residual impacts are as low as reasonably achievable;
(3) To ensure that the waste storage is physical stable;
(4) To determine, if necessary, the future uses of the landscaped areas;
(5) To favour integration into the surrounding landscape.

To this end, the activities implemented were as follows:

➔ Preliminary studies of the effectiveness of the containments and geotechnical constraints.

The effectiveness of the containments was examined by measuring the radon flux values and gamma proton flow rates from a series of trial plots that had different structures and cover depths.

The cover products tested were those that could be collected from areas near the installations (mining tailings: tailings outside the mining site; laterite).

➔ Site restoration work from mid 1997 to the end of 2000.

This work has made it possible to:

— Group together products to be managed, to limit as far as possible the areas likely to constitute a radiological impact for the exposed population,
— contain under water or under a solid cover, the products to be managed, taking geotechnical and radiological constraints into account.

These containments must limit the gamma dose flow rates and radon flow levels to rates that are comparable to those measured in the regional natural surroundings (80 to 150 $nGy.h^{-1}$; 0.04 to 0.1 $Bq.m^{-2}.s^{-1}$).

The most important work was:

— The construction of a new dike to supplement the existing dikes on the river Gamaboungou. The new dike, which is 200 m long with a maximum height of 11 m, was constructed using 500 000 m^3 of broken rock and laterite. This construction guarantees a minimum water depth of 1 m over the 6 ha area where the process tailings are stored in the central part of the Gamaboungou valley.

— The reshaping and containment of the Mounana open pit, which is located in the upper part of the Gamaboungou valley. A solid cover was emplaced using 500 000 m^3 of broken rock and laterite. The cover was designed to resist the heavy rains of the Mounana region. Approximately 50 ha were remediated using this technique.

In addition to these extensive undertakings, all of the areas which contain radioactive materials (process tailings, low grade ore, settlement sludge ...) were covered with at least a 0.70 m thickness of laterite.

The two milling facilities have been dismantled. The wooden components of the first mill were burned. The metallic parts and the materials were, after cleaning and radiological examination, offered to potential users or were buried in the Oklo open-cast mine, which also has a water cover. This water cover will be about 80 m deep when the open cast pit is completely filled in 2001. This procedure will guarantee isolation of the dismantling products, without disturbing the radiological properties of the waters.

In order to integrate and blend the remediated areas into the landscape and also to reduce the effects of the equatorial rains to a minimum, a major part of the recovered areas have been replanted. This was carried out using local vegetation to guarantee the desired effects; the vegetation cover was planted by the local population using traditional techniques.

2.3. Stage 3: setting up radiological monitoring on the site

This stage, which was initiated after the restoration was completed, consisted of setting up a radiological monitoring network. Measurements taken in the air and water vectors, on the food chain and on certain bio-indicators (sediments and plants), enabled the following work to be carried out:

- inspecting the effectiveness and timelessness of the restoration work;
- assessing the effective annual dose generated by the remediated site for the identified critical groups;
- checking for compliance with all of the fixed objectives.

The monitoring network is composed of:

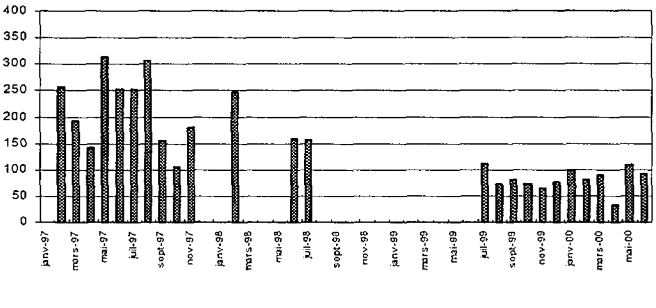
- Eleven fixed stations for measuring the integrated monthly alpha energy of short life daughters of radon using alpha site dosimeters. These stations were positioned as follows:
  - Five stations in the inhabited areas of the environment close to the site,
  - Three stations in the industrial areas of the site,
  - Two stations in the tracks crossing over the restored site,
  - One station in the natural surroundings outside the influence of the site.
- Twenty fixed stations for measuring the integrated monthly gamma dose flow rate using thermoluminescent dosimeters. These fixed stations were located in the following areas:
  - Five in inhabited areas,
  - Three in work areas,
  - Eleven in crossing tracks,
  - One in the natural surroundings.
- Twelve water testing stations for the measurement of radium 226 and uranium, including:
  - Six stations for biannual testing of the drinking water in villages in the close environment and the natural surroundings,
  - Three stations for the monthly testing of water likely to be flowing from the site towards the receiving environment,
  - Three stations for the monthly testing of the receiving environment (the rivers Mitembe and Lekedi downstream from the site).
- Three stations for biennial testing of produce grown and consumed by the inhabitants, for determining the mass activities of radium 226, uranium, thorium 230 and lead 210;
- Four stations for biennual testing of fish likely to be caught and consumed by the inhabitants, for determining mass activities of radium 226, uranium, thorium 230 and lead 210;

— Three stations for biennual testing of bio-indicators (sediments and plants), for determining the mass activities of radium 226, uranium, thorium 230 and lead 210 in the two receiver watercourses downstream from the site and also on the replanted site.

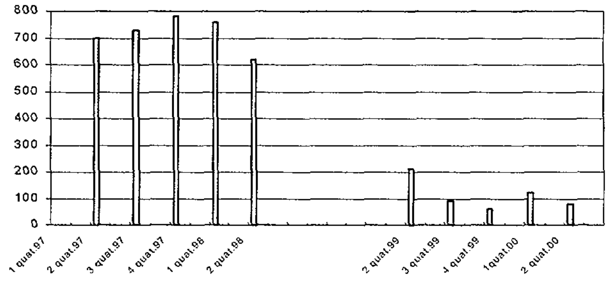
The following graphs show an example of the effectiveness of the restoration. The measurements were made at (1) the atmosphere monitoring station positioned on the Mounana quarry, (2) in an area where inhabitants pass through, and (3) at the station for testing the surface waters in the environment downstream from the site.

COMUF - MOUNANA OPEN PIT - TAILINGS STORAGE

Radon daughters Potential Alpha Energy
PAE - nJ / m^3

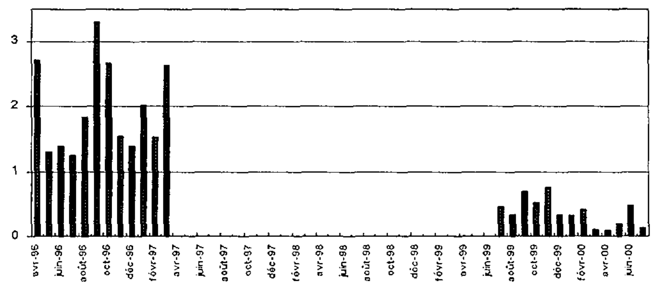


GAMMA Dose Rate
nSv.h^{-1}



COMUF - MITEMBE RIVER - MASSANGO VILLAGE DOWN STREAM

Soluble Ra226
Bq . l^{-1}



Soluble U238
mg . l^{-1}

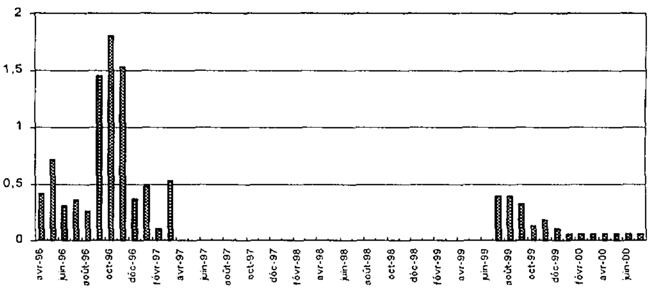


Table 2 shows that in late June 2000, after completion of all site restoration work (except for the area downstream of the Gamaboungou valley), the effective added dose for the two reference groups is close to 1 mSv, i.e. a reduction by a factor of 2 to 3 in relation to the situation before restoration (see Table 1).

The effective dose is calculated from measurement results supplied by the fixed stations during the first six months of 2000. The exposure levels associated with the ingestion of radionuclids (drinking water and food chain) remain identical to those of the natural level and do not produce any added dose.

TABLE 2. EFFECTIVE ADDED DOSE FOR THE REFERENCE GROUPS IN JUNE 2000

During restorion (01/2000 → 06/2000)	Pathways				Effective Added Dose in mSv
	PAE Rn222 nJ.m^{-3}	PAE Rn220 nJ.m^{-3}	LLAE mBq.m^{-3}	Gamma nGy.h^{-1}	
Reference group RG1					
Time spent in the environment	84	20	< 1	140	0.37 +
Work on the industrialized site	81	18	< 1	250	0.34 +
Travel over the Mounana site	84	21	< 1	100	0.02 + = **0.97**
Work in the plantations	84	20	< 1	100	0.02 +
Travel in the Gamaboungou valley	183	32	2	1970	0.22
Reference group RG2					
Time spent in the close	84	20	< 1	140	0.35 +
environment	80	20	< 1	100	0.12 +
Work in the plantations	183	32	2	1970	0.74 + = **1.23**
Travel in the Gamaboungou valley	84	21	< 1	100	0.02
Travel over the Mounana quarry					
Natural level					
Village of Omoï	35	18	< 1	130	

3. CONCLUSION

The restoration work at the Mounana site was undertaken in July of 1997 and was continued during each dry season for the years 1998, 1999 and 2000. By the end of June 2000, the restoration work that had been completed made it possible to achieve and effective radiation dose for the critical population groups that was only 1 mSv in excess of the natural radiation exposure. The essentially uninhabited downstream area of the Gamaboungou valley has not yet been remediated. This area is scheduled to be sealed with a laterite cover in 2001 and the watercourses channelized using layers of broken rock. It is anticipated that this restoration will limit the dose to individuals passing through the area to a gain of about 0.12 mSv for each 100 hours of exposure.

Also, by the end of 2001, the Mounana site-monitoring network which is managed by a local branch of the Ministry of Mines of Gabon, will enable an effective added dose to be calculated for the most exposed inhabitants. Projections indicate an added dose of about 0.80 mSv per year; this dose will meet the objectives that had been fixed for the redevelopment of the Mounana site.

The planned monitoring period, which will continue after final restoration of the site will confirm the timelessness of the undertaken actions.

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REGULATORY AFFAIRS

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