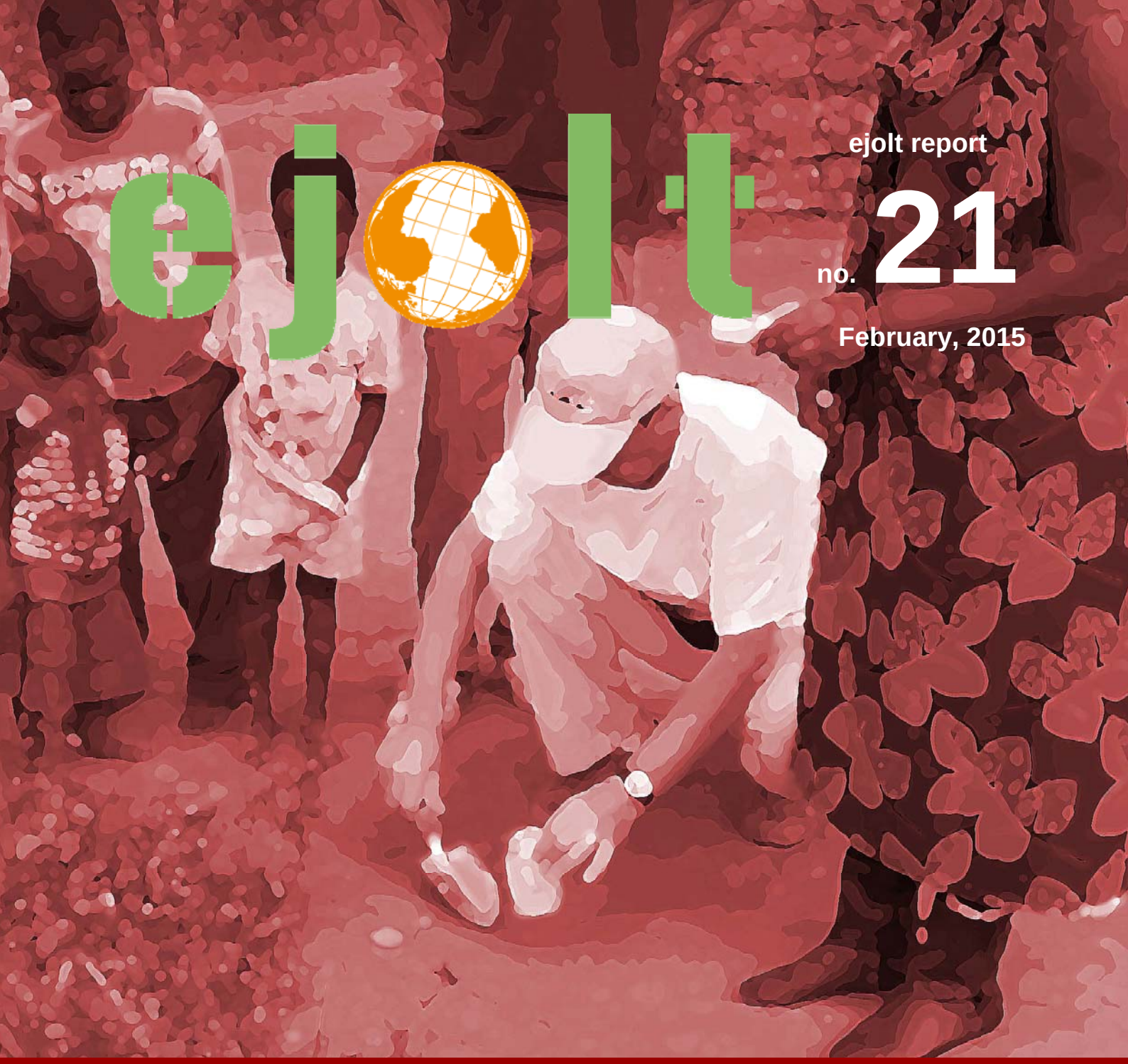

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no. 21

February, 2015

Impact of the Kayelekera uranium mine, Malawi

Report written by Bruno Chareyron

EJOLT Report No.: 21

Impact of the Kayelekera uranium mine, Malawi

Based on CRIIRAD and CFJ May 2012 mission in Malawi

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This publication was developed as a part of the project Environmental Justice Organisations, Liabilities and Trade (EJOLT) (FP7-Science in Society-2010-1).

EJOLT aims to improve policy responses to and support collaborative research and action on environmental conflicts through capacity building of environmental justice groups around the world.

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Abstract

In the course of the EJOLT project, the CRIIRAD laboratory conducted in May 2012 radiation monitoring activities in the surroundings of the uranium mine commissioned by Paladin Africa Limited (PAL) in Kayelekera (Malawi). Radiation monitoring training activities were also performed with CFJ (Citizens for Justice) and the local communities in Kayelekera. CRIIRAD discovered hot spots in the environment of the mine and a high uranium concentration in the water flowing from a stream located below the open pit and entering the SERE river. Results that relate to the radiological monitoring of the environment performed by the company are kept secret. The company should publish on its web site all environmental reports. No property right can be invoked to prevent public access to Paladin environmental reports (especially as Malawi State holds 15 % of the shares of the uranium mine). It is shocking to discover that million tonnes of radioactive and chemically polluting wastes (especially tailings) are disposed of on a plateau with very negative geological and hydrogeological characteristics. This report will be used during new training and sampling activities to be performed by CRIIRAD and CFJ in February 2015.

Keywords

uranium
uranium mining
waste rocks
tailings
contamination
Paladin
Kayelekera
Malawi
water contamination

Contents

Acronyms

Bq	becquerel
CRIIRAD	Commission de Recherche et d'Information Indépendantes sur la RADioactivité
CFJ	Citizens for Justice (Malawi)
CSO	Civil Society Organizations
EC	European Communities
EIA	Environmental Impact Assessment
EJO	Environmental Justice Organizations
ICRP	International Commission on Radiological Protection
mSv	milliSievert
µSv	microSievert
PAL	Paladin Africa Limited
TSF	Tailings Storage Facility
UAB	Universitat Autonoma de Barcelona
WHO	World Health Organization

Foreword

This publication was developed as a part of the project Environmental Justice Organisations, Liabilities and Trade (EJOLT) (FP7-Science in Society-2010-1). The EJOLT project “Environmental Justice Organizations, Liabilities and Trade” is a project funded by the European Community under the seventh framework programme. The project coordinated by UAB (Universitat Autonoma de Barcelona) unites a consortium of international actors (scientists, activist organizations, think-tanks, policy makers across a range of fields (environmental law, environmental health, political ecology, ecological economics) to promote mutual learning and collaboration of stakeholders who make use of Sustainability Sciences, particularly on aspects of Ecological Distribution. EJOLT aims to improve policy responses to and support collaborative research and action on environmental conflicts through capacity building of environmental justice groups around the world.

The EJOLT project (2011-15) has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement no 266642. The views and opinions expressed in the website and in all EJOLT publications and documentaries including the Atlas reflect the authors’ view and the European Union is not liable for any use that may be made of the information contained therein.

The present report is comprising 7 sections. Section 1 gives general information about radiation, uranium mining and a short presentation of Kayelekera uranium mine. Section 2 describes the mission conducted by CRIIRAD and CFJ at Kayelekera in May 2012. Sections 3 to 6 gives the results of environmental monitoring activities performed by CRIIRAD in May 2012. Section 7 provides recommendations.

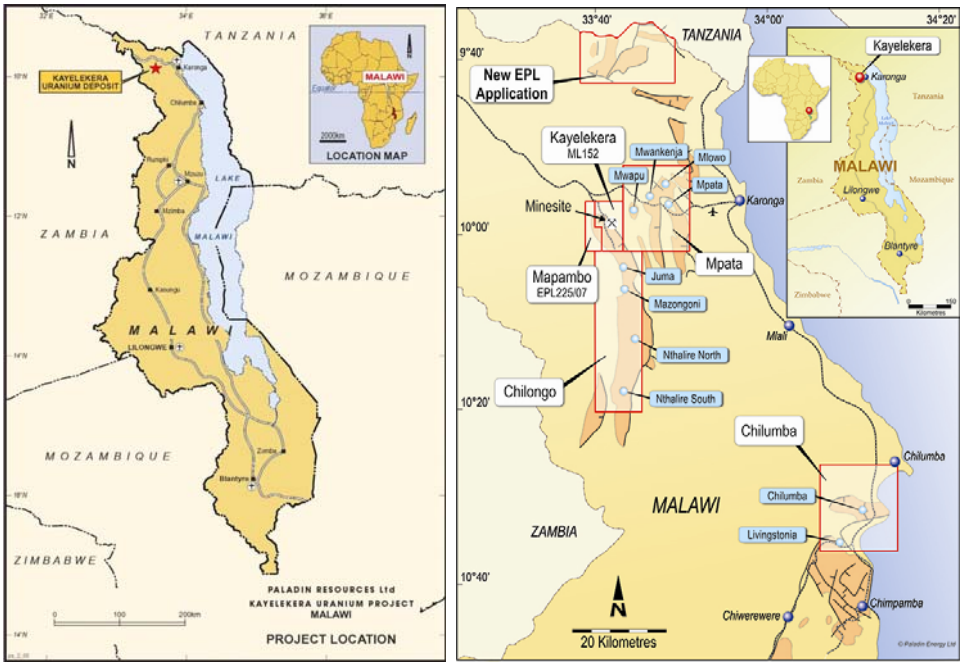
1 The Paladin uranium mine in Kayelekera

Malawi is located in the southern part of Africa (see **Figs. 1-2** below). Several uranium deposits have been discovered in Malawi and one uranium mine has been put in operation near the village of Kayelekera, about 52 kms west (by road) of the provincial town of Karonga, in the northern part of the country, about 575 km north of the capital city, Lilongwe (see **Fig. 2** below).

Figs. 1-2

Map of Malawi and location of the Kayelekera deposit and location of the Paladin uranium extraction and prospection areas

Source: Paladin website, Sept 2014



1.1 General information about Kayelekera uranium mine

The operator is “Paladin Africa Limited (PAL)” owned by an Australia based company (Paladin). The Mining Licence was granted in April 2007. According to the company “open pit mining commenced in May 2008 to develop initial stockpiles, with the first blast occurring on 24 July 2008. The mine has been designed to provide an annual production of 3.3 Mlb U3O8 from the processing of 1.5 million tonnes per annum of sandstone and associated ores by grinding, acid leaching, resin-in-pulp extraction, elution, precipitation and drying to produce saleable product.”

The site comprises an open pit, a uranium extraction plant and various facilities for interim storage or permanent storage of different types of waste produced by the mine (waste rocks placed into waste rock dumps) and the mill (tailings placed into Tailings Storage Facilities or TSF).

The final product (uranium concentrate) called “yellow cake” is put in 200 liters drums, arranged in containers and transported by truck to port facilities.

In February 2014, Paladin Energy Ltd announced that its subsidiary company, Paladin (Africa) Limited (PAL), was suspending production at its Kayelekera Mine: “The suspension involves placing the Operation on care and maintenance until the price of uranium recovers. This decision will preserve the remaining ore body until a sustained price recovery occurs and Paladin determines that production may be resumed on a profitable basis.”

Figs. 3-4

Entrance to Paladin‘s mine and view of a waste rock dump

Source. CRIIRAD, May 2012

1.2 General introduction about natural radiation

When uranium mining occurs, uranium ores are brought into the surface.
Uranium ores have a high uranium content and emit therefore higher levels of radiation than usual soils or rocks

At the surface of planet earth, in all continents, there are natural levels of radiation in the soil, water, air, flora and fauna. A significant fraction of this radiation is due to radioactive elements naturally present in the earth crust: uranium 238, uranium 235, thorium 232 and potassium 40. The reader will find more detailed information about radiation in EJOLT report N°15[1].

Natural uranium (uranium 238, uranium 235 and their daughter products) is present in all rocks and soils.

[1] Ejolt Report N°15: http://www.ejolt.org/wordpress/wp-content/uploads/2014/11/141115_U-mining.pdf

Radioactive elements associated with uranium are also naturally present in the air in the lower atmosphere: dust from the soil, along with radon (a radioactive gas) which is permanently emanating from the rocks and soils containing uranium.

These radioactive elements are also present in surface and underground waters in contact with the soils and rocks containing uranium, as well as in the crops, flora and fauna and therefore the food chain.

The radiation emitted by these radionuclides is called natural background radiation.

The typical total activity concentration of the uranium ore at Kayelekera is exceeding 119 000 Bq/kg, while the mean activity of the earth crust is below 2 000 Bq/kg.

1.3 Radioactivity of the uranium ore at Kayelekera

When uranium mining occurs, uranium ores are brought into the surface. Uranium ores have a high uranium content and emit therefore higher levels of radiation than usual soils or rocks.

According to Paladin 2006 EIA report (ES-1), the Kayelekera deposit is a sandstone-hosted uranium deposit. The mineralised lenses are located within distinct arkose units and occur to a depth of approximately 100 m from surface.

The resource is said to contain approximately 13 600 tonnes of recoverable uranium (as U3O8) with a grade of approximately 800 ppm (U3O8), which means that the activity[2] of uranium 238 is about 8 500 Bq/kg.

The activity is the amount of radioactive atoms that are disintegrating per second in a given amount of material.

The typical total activity concentration of the uranium ore at Kayelekera, calculated including the thirteen daughter products of uranium 238, along with uranium 235 and its own daughter products, is therefore exceeding 119 000 Bq/kg while the mean activity of the earth crust is below 2 000 Bq/kg.

This means that more than 100 000 radioactive atoms are disintegrating in each kilogram of ore every second and are emitting dangerous ionizing radiation[3] accordingly (mainly alpha, bêta and gamma radiation).

1.4 Mechanisms through which uranium mining increases the level of exposure to radiation

Uranium ore has to be managed with a great deal of caution due to the risks of exposure to ionizing radiation for the workers and local population living in the surroundings of the mine.

[2] Ejolt Report N°15, page 15-19: http://www.ejolt.org/wordpress/wp-content/uploads/2014/11/141115_U-mining.pdf

[3] Ejolt Report N°15, page 15-34: http://www.ejolt.org/wordpress/wp-content/uploads/2014/11/141115_U-mining.pdf

All the production processes in the mining operations, from extraction and crushing of ore to uranium milling and manufacturing of the yellow cake, are transferring radionuclides into the biosphere

When the uranium ore is buried underground – at a depth of one hundred meters - the radiation levels at the surface of the soil remain low and usually have the same order of magnitude of natural radiation levels.

Exceptionally, some areas of a limited extension (a few square meters) can be found where the ore reaches the ground surface. Otherwise, the protection offered by the soil is usually sufficient to reduce the risks for the people living in the area. Indeed, alpha and low energy beta particles are stopped by a thin layer of soil (much less than 1 cm). Even penetrating gamma radiation does not cross a layer of soil of a few meters. Most of the radon gas remains trapped inside the soil. Because of its short half-life (3.8 days) a lot of the gas atoms will disintegrate inside the soil during their migration before reaching the biosphere.

In terms of underground water quality, the amount of nuclides may remain low if the minerals containing uranium are trapped in impermeable layers.

In areas with high uranium concentration in the rocks, the population is usually exposed to higher than usual radiation doses. This is the reason why specific monitoring activities have to be implemented like the monitoring of radiation of the water used for human consumption and the monitoring of radon activity in the air. Specific techniques can be used to lower the doses to the public like special building techniques (in order to reduce indoor radon accumulation) or water treatment. But the extraction of uranium increases the exposure of the local population to ionizing radiation.

All the production processes in the mining operations, from extraction and crushing of ore to uranium milling and manufacturing of the yellow cake, are transferring radionuclides into the biosphere. This should be taken into account when calculating the dose to the workers and affected populations:

- • Uranium mining usually increases the amount of uranium and its daughter products in surface and/or underground water. Some of these radioactive metals are very radiotoxic when ingested. Lead 210 and polonium 210, for example, are among the most radiotoxic radionuclides.
- • Radioactive dust is transferred to the atmosphere by mining operations, blasting, extraction and crushing of the ore, uranium milling, management of waste rocks and tailings. Radon gas is transferred to the atmosphere by diffusion from radioactive rocks and tailings.

Radioactive waste is produced by a uranium mine in many different forms increasing the ambient dose rates for workers and people living in the vicinity of these materials.

These include solid waste (waste rocks, tailings, contaminated equipment, etc.) and liquid effluents. If these solid or liquid wastes are stored without proper confinement, airborne and water contamination will take place.

Huge amounts of radioactive waste rocks (rocks not treated in the mill), with activities exceeding the normal natural activity of the earth crust by one to two orders of magnitude are accumulated in uncovered waste rock dumps. In some countries, including France, Niger or Gabon, radioactive waste rocks have been

dispersed into the environment and used for landfill, road construction and even building[4].

In the case of Kayelekera uranium mine, Paladin is intending to use a cut-off value of 300 to 600 ppm (see Fig. 5 below). Rocks with a uranium concentration of 300 ppm U3O8 have a Uranium 238 activity slightly above 3 000 Bq/kg which is 75 times above the mean activity of the earth crust. The dose rate above a road or a platform filled with such waste rocks may exceed 1 µSv/h (microSievert per hour), which means an annual cumulative dose in excess of the annual dose limit of 1 milliSievert per year if people spend more than 1 000 hours per year in such places (this calculation is based on external irradiation without considering the internal contamination due to inhalation of radon gas permanently emanating from the waste rocks).

Fig. 5

Summary of uranium resource estimate at Kayelekera

Source: Hellman and Schofield 2006 resource estimate, PALADIN EIA 2006 report, 6-20

At 300ppm U_3O_8 Cut-off

	Mt	Grade % U_3O_8	Tonnes U_3O_8
Measured Resources	2.20	0.12	2,730
Indicated Resources	13.11	0.08	10,880
Total	**15.31**	**0.09**	**13,630**
Inferred resources	**3.40**	**0.06**	**2,040**

At 600ppm U_3O_8 Cut-off

	Mt	Grade % U_3O_8	Tonnes U_3O_8
Measured Resources	1,58	0,16	2 460
Indicated Resources	6,98	0,12	8 240
Total	**8,56**	**0,12**	**10 690**
Inferred resources	**1,19**	**0,09**	**1 110**

Huge amounts of radioactive tailings (with typical total activities exceeding 100,000 and even 500,000 Bq/kg) are generated by milling operations. They are the radioactive waste left after the ore is processed. They contain all the radioactive metals of the uranium decay chain which have not been extracted in the mill, especially thorium 230 and radium 226 whose half-lives are 75,000 years and 1,600 years respectively. Some of these radionuclides have a very high radiotoxicity).

Tailings are usually stored without proper confinement[5] and in contradiction with the three management rules that apply to this kind of radioactive waste : 1 / select a geologically suitable location ; 2 / build storage capacities to ensure long term isolation of the waste from the biosphere ; 3 / pack the waste in sealed drums or containers. The only justification of the French authorities is that, given the amount of waste (50 million tonnes in the case of France), the cost of a proper waste management strategy would be too high.

[4] Ejolt Report N°15, page 45-50: http://www.ejolt.org/wordpress/wp-content/uploads/2014/11/141115_U-mining.pdf

[5] Ejolt Report N°15, page 51-57: http://www.ejolt.org/wordpress/wp-content/uploads/2014/11/141115_U-mining.pdf

According to Paladin, 9.1 Mm3 of waste rocks will be produced

In some cases (for example in Gabon), the tailings have also been discharged directly in the environment.

Of major concern is the possible contamination of surface and underground waters, transportation through the air of dust, radon gas and gamma radiation, and the stability of the tailings dams themselves. Dams generally used to contain these tailings have failed in several occasions[6].

Contaminated liquid effluents also pose a considerable risk due to limitations in their treatment before they are discharged into the environment. In the case of France[7], for example insufficiently treated waters from uranium mines actually contaminate the environment: sediment, fish, aquatic plants (in France, CRIIRAD discovered that aquatic plants located downstream of uranium mine effluent discharges had contamination levels exceeding 100 000 Bq/kg dry).

It should be stressed that even decades after the shutdown of uranium mines and mills, the radioactive contamination of the environment remains. This is due to the fact that uranium 238 half-life is very long (4.5 billion years). Uranium 238 will always be present in the different types of waste, decaying into its daughter products.

1.5 Amount of radioactive material at the Kayelekera uranium mine

Open pit, waste rock dumps and marginal ore dump

The final open pit dimensions are expected to be in the order of 300 m wide (east-west), 600 m long (north-south) and 130 m deep (2006 EIA report, ES-5). According to the information given by Paladin to the Parliamentary Committee for Natural Resources and Climate Change in October 2014, “the open pit is 1 kilometre long, 500 metres wide and 100 metres deep. It contains 14 million tonnes of ore and 31 million tonnes of waste rock. When all the dumps are constructed, the final disturbed area will be 2.8 square kilometres”.

According to Paladin sustainability reports (2012 and 2013); during the period 1 July 2011 to 30 June 2012, 1.89 million tons of waste rock have been moved. This amount has been increased to 3.4 million tons during the period 1 July 2012 to 30 June 2013. The surface of the waste rock dump area was 62 ha (June 2013).

According to Paladin (2006 EIA report, 2-9), 9.1 Mm3 of waste rocks will be produced of which 5.2 Mm3 will be used in the construction of the Tailings Storage Facility dams and walls.

According to Paladin, some of this radioactive material is intended to be re-used as: “Construction of road surfaces, engineered terraces, the pollution control dam

[6] See Wise uranium : http://www.wise-uranium.org/mdaf.html

[7] Ejolt Report N°15, page 37-39: http://www.ejolt.org/wordpress/wp-content/uploads/2014/11/141115_U-mining.pdf

and the raw water dam will also require the use of additional quantities of this waste material".

The waste rocks not being used for construction will be stored in a waste rock dump (WRD) and marginal ore dump (MOD) depending on the level of radiation as described below:

"Marginal Ore:

• Arkose material containing 200 to 400 ppm U3O8

• Mudstone material containing 600 to 800 ppm U3O8

Waste Rock:

• Clean arkose containing < 100 ppm U3O8

• Clean mudstone containing < 100 ppm U3O8

• Mineralised arkose containing 100 to 200 ppm U3O8

• Mineralised mudstone containing 100 to 600 ppm U3O8"

The marginal ore will be stockpiled for potential future processing depending on the uranium market.

Tailings dumped into the TSF (Tailings Storage Facility)

During the periods 1 July 2011 to 30 June 2012, and 1 July 2012 to 30 June 2013, respectively 1.17 million and 1.38 million tons of tailings (dry) have been produced. The surface of the TSF area is 49 ha (June 2013). The TSF wall has been heightened by around 4 m during the period 2012/2013 in order to increase the capacity volume by around 1 Mm3.

The tailings are stored in "TSF A" located in the south-east of the mine site on the right bank of the Sere river catchment (see Fig. 6 below). According to Paladin "TSF A will fill practically the whole of the Kantchindu valley. A seepage detection dam has been built in the Kantchindu valley downstream of the main tailings dam to intercept any seepage that may leak through the basin lining and grout curtain. Any collected seepage water will be pumped back into the tailings basin" (2006 EIA report, ES-10).

Fig. 6

Aerial view of the Kayelekera uranium mine, Tailings Storage Facility (TSF A) and raw water ponds

Source: https://mininginmalawi.files.wordpress.com/2014/11/kayelekera-mine-site-layout.png

It should be noted that the disposal facility designed by Paladin will not guarantee confinement of the hazardous wastes after 250 years

Another TSF (TSF B) is planned at the northwest when TSFA will be full. Paladin is planning to produce 13 million tons of tailings on a 9 year period.

Radioactive contaminated wastes and hazardous wastes

According to Paladin (2006 EIA report, ES-13), “Apart from the tailings described above, other radioactive wastes that could be generated by the Project include process related waste and equipment such as scrapped pipes, tanks and valves. Rubber lined equipment in contact with process liquids, especially acidic solutions, can become significantly radioactive. Soils contaminated by product as well as sludges from the process plant are also considered as radioactive wastes in circumstances where these cannot be returned to the process”.

During the periods 1 July 2011 to 30 June 2012, and 1 July 2012 to 30 June 2013, respectively 1 759 and 3 558 tons of radioactive contaminated waste have been produced.

As Malawi has no facilities for the appropriate disposal of hazardous and radioactive wastes, Paladin is disposing such wastes directly on site. According to Paladin EIA report (page ES-14) :

“Conventional hazardous waste (non-radioactive) is to be disposed of in a suitably prepared contaminated waste disposal site. The waste disposal site will meet the requirements of the Malawian Bureau of Standards that leakages of hazardous materials to groundwater will not occur within a period of 250 years (MBS, 2005a).”

“Radioactively contaminated process equipment to be disposed of on-site or refurbished off-site will first be decontaminated and then screened for surface contamination before being released. A dedicated wash bay will be provided and equipped with highpressure water jets to clean equipment. Other radioactive wastes arising, for example, radiation contaminated soils or radioactive sludges collected in process areas, will preferentially be returned to the process plant. If these materials are not adequate for processing, they will be disposed of in the TSF.”

It should be noted that the disposal facility designed by Paladin will not guarantee confinement of the hazardous wastes after 250 years.

Uncontrolled discharge of liquid effluents

According to the 2006 EIA report (page ES-11), “Under normal operating conditions there will be no discharge of water or effluents from the Kayelekera Uranium project”.

Even when the effluents are transferred to containment pools for evaporation, the risk of spills still remain. At more or less all uranium mines, spills do occur.

Kayelekera mine is not an exception. Various spills occurred for example in March 2013 and January 2015.

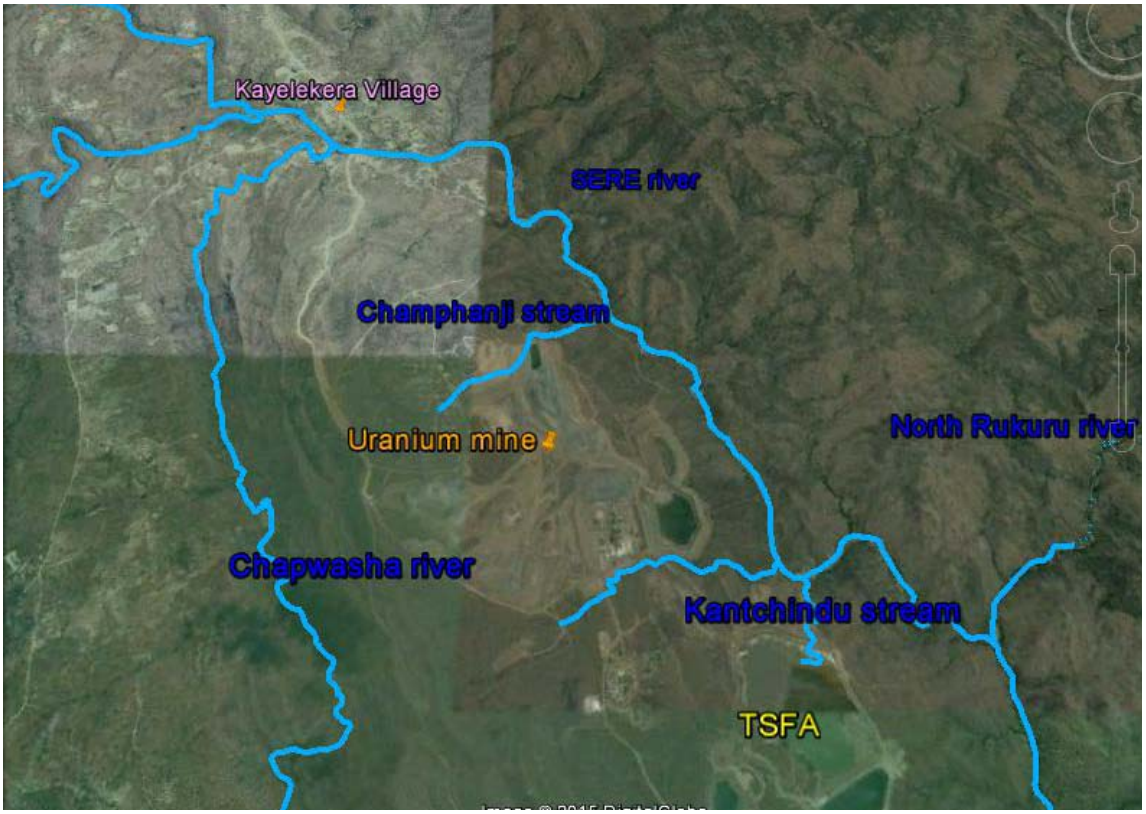


Fig. 7

Aerial view of the Kayelekera uranium mine, Tailings Storage Facility, and main rivers and streams

Source: GoogleEarth-CRIIRAD

According to Paladin Sustainability report (2013), in March 2013, "heavy rainfall caused a surface water capture and diversion drain to breach resulting in runoff water from the Run-of-Mine stockpile area and waste rock dumps entering the environment. Equipment was immediately mobilised to repair the drain and the surface water quality monitoring programme was extended to sample the surface water quality in the affected stream on a more frequent basis. This incident was also reported to the Authorities and a full investigation undertaken". Unfortunately, Paladin report gives no details about the degree of radiological and chemical pollution of the stream and rivers located downstream. A detailed report should be produced and made public.

Various spills occurred at Kayelekera mine for example in March 2013 and January 2015.

Other spills occurred at Kayelekera uranium mine in January 2015.

Paladin announced[8] that on 5 January 2015 there has been some "minor storm damage" at the mine. "A 20-minute, high-intensity storm resulted in some 25 mm of rain falling at the Site. The resultant surge of stormwater caused the liner in the plant run-off tank to rupture, releasing up to 500m3 of material to the bunded areas of the site. Up to 0.05m3 (50 litres) may have overtopped one of the containment bunds due to the nature of the rainfall event at the time. Following discovery of the damaged tank, the Company immediately commenced protection and remediation procedures and the site remains secure. A sampling programme to analyse water from within the local stream system was also initiated to confirm

[8] ir.paladinenergy.com.au/DownloadFile.axd?file=/Report/ComNews/20150107/01589895.pdf

no contamination occurred. The Company has formally advised relevant Government of Malawi authorities of the incident".

A detailed report should be produced and made public, but again, this is not the case. Paladin press release of February 10Th 2015 states "All results demonstrated that no measurable contamination had occurred as a consequence of the event" but no detailed results are provided. Therefore, it is not possible to check if the monitoring strategy was appropriate or not (location of the samples, time of sampling, list of parameters being monitored, detection limits, etc..).

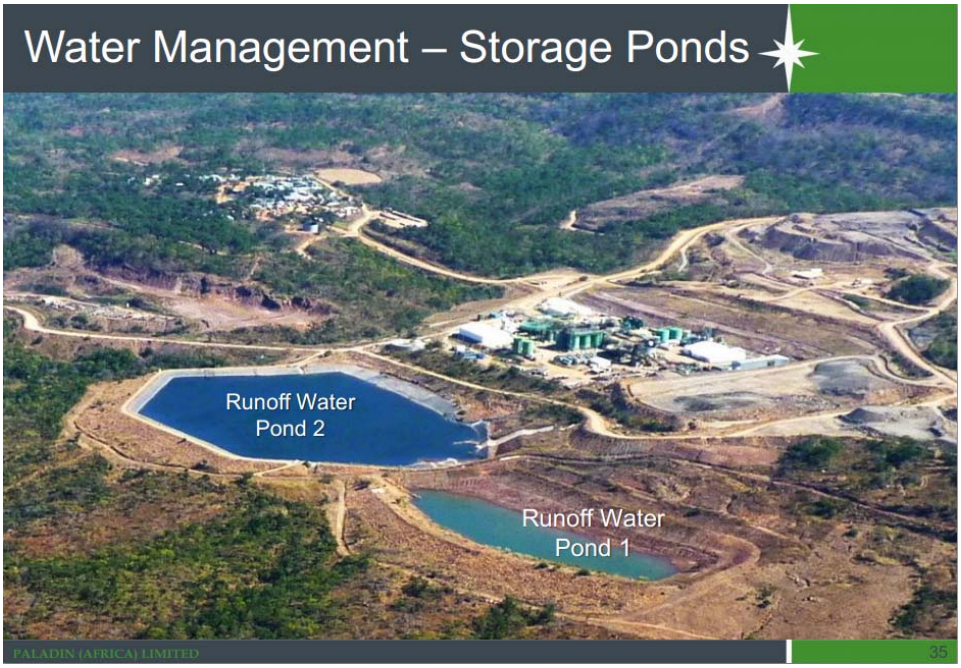


Fig. 8

Aerial view of the Kayelekera uranium mine runoff water ponds

Source: https://mininginmalawi.files.wordpress.com/2014/11/water-management-storage-ponds-at-kayelekera-uranium-mine.png

Controlled discharge of liquid effluents

In contradiction with the statements of the 2006 EIA report, Paladin (Africa) Limited (PAL) confirmed on November 20th 2014 that it "plans to begin the controlled release of surplus water into the local river system in early 2015, but only after treatment to meet Malawi and internationally recognised discharged standards, including the World Health Organisation (WHO) drinking water guideline for uranium content…/… The water filtration process to be used is simple and widely used in the water treatment industry. PAL has conducted test work for several months and has been very successful in treating water to the WHO standard for drinking water…/…This controlled water release is necessary to avoid any possible unplanned discharge of run-off water contained in storage ponds at Kayelekera Mine during the period of Care and Maintenance…".

In fact, during production operations, captured run-off water is used and recycled in processing of uranium ore. But as the mine ceased production on 21 May 2014, the amount of water to be captured is increasing.

Additional information about Paladin projects is given in **Appendix 4**.

2 Context of CRIIRAD May 2012 mission to Kayelekera

2.1 Presentation of CFJ and CRIIRAD

CFJ (Citizens For Justice) is a Malawian NGO based in Lilongwe, the capital city of Malawi. CFJ is concerned by the environmental impact of the Kayelekera uranium mine.

CRIIRAD (Commission de Recherche et d'Information Indépendantes sur la Radioactivité) is a French NGO specialized in radiation monitoring. CRIIRAD goal is to inform the general public about the risks induced by ionizing radiation and to improve its protection against such risks. CRIIRAD is operating its own laboratory in Valence (France) in order to analyze environmental samples. CRIIRAD laboratory team is comprising 8 technicians and Engineers and is accredited by the French Nuclear Safety Authority (ASN). CRIIRAD has been working for more than 20 years on the monitoring of the radiological impact of uranium extraction in Europe (France, Finland, Bulgaria), Africa (Niger, Gabon, Mali, Namibia), Brazil, etc.

CRIIRAD and CFJ have become partners under the EJOLT project (Environmental Justice Organisations, Liabilities and Trade), funded by the EC (FP7-Science in Society-2010-1). EJOLT (www.ejolt.org) aims to improve policy responses to and support collaborative research and action on environmental conflicts through capacity building of environmental justice groups around the world.

In the course of the EJOLT project, CRIIRAD has been able to conduct a preliminary mission to Kayelekera in May 2012 in order to organize a transfer of knowledge to CFJ and local communities in the area of independent monitoring of the radiological impact of uranium mines.

In the course of the EJOLT project, CRIIRAD has been able to conduct a preliminary mission to Kayelekera in May 2012 in order to organize a transfer of knowledge to CFJ and local communities

During this mission, CRIIRAD managed to make on site monitoring of gamma radiation and collect samples for additional analysis.

The sampling programme was very limited and preliminary, it should not be considered as a comprehensive radio-ecological study but only as the first step of a process that may lead to the design of an independent monitoring strategy and give preliminary results to the communities in order to initiate a dialogue with the company and governmental bodies.

Figs. 9-10

View of Kayelekera village: picture on the left is taken from the mine area, picture on the right is taken from the village, dust from blasting at the mine is visible

Source: CRIIRAD, May 2012

During the May 2012 mission to Kayelekera, CFJ team comprised M William Nyirenda, Coordinator for Environmental Justice and Mrs. Chikondi Njawala, coordinator for Social Justice. On the first meeting with the Community in Kayelekera, the team could also benefit from the input of Mr. Innocent Mwalwanda, CFJ delegate based in Karonga.

CRIIRAD team comprised M. Bruno Chareyron, engineer in nuclear physics, head of the CRIIRAD laboratory and M. Christian Courbon, specialized technician in charge of onsite surveys.

In order to prepare the sampling programme, M. Chareyron, studied Paladin 2006 EIA report (Environmental Impact assessment).

Unfortunately, Paladin website is not providing detailed information about the environmental situation at Kayelekera. Such a lack of information is deeply limiting the work of the NGO's and local communities.

CRIIRAD is willing to work as closely as possible with CFJ at all stages of the study process: sampling, on site radiation monitoring, interpretation of results, communication with different groups (villagers, workers, government bodies, local authorities, and the mining company).

2.2 Communication and training activities performed in May 2012

CRIIRAD team trained CFJ members in Lilongwe in the following areas: basics about radioactivity and radiation, alpha and gamma radiation, uranium decay chain, typical ambient doserate on earth, use of a portable radiation monitor (RADEX and DG5), typical radon concentration in the open air, etc…

Radiation measurements were performed in CFJ garden and for comparison on a sample containing a small amount of uranium.

During CRIIRAD on site mission to Kayelekera, CFJ staff participated in the sampling programme which included discussions about the sampling strategy and preliminary interpretation of the radiation readings, the measurement of ambient gamma doserate with a portable radiation monitor (Radex) and comparison with gamma flux measurements performed with a professional scintillometer (DG5).

During the last day of the mission, M. Nyirenda from CFJ performed the last sampling of surface water and surface sediments.

Figs. 11-12

CRIIRAD team is training CFJ members in Lilongwe (May 2012), Radex Geiger Mueller counter (left) / DG5 scintillometer (right)

Source: CRIIRAD, May 2012

Figs. 13-14

CFJ member M. Nyirenda is sampling surface water and sediments in the North Rukuru river

Source: CRIIRAD, May 2012

2.3 Cooperation with the local Community in Kayelekera (May 2012)

On arrival to Kayelekera, a meeting was organised with the community including Kayelekera village chief and its councillors, primary school headmaster, secondary school headmaster, teachers, teenagers and elders.

M Chareyron introduced CRIIRAD, gave basic information about the radiological impact of uranium mines based on CRIIRAD studies performed in France, Niger and Gabon and described the sampling programme that CRIIRAD was intending to perform at Kayelekera with the cooperation of the community. Translation between English and the local language was performed by M Nyirenda (CFJ).

CRIIRAD used a portable Geiger Mueller counter (RADEX) to illustrate the nature of invisible radiation from uranium and the effect of distance between the source of radiation and the people.

On Sunday, CRIIRAD displayed a film about the impact of uranium mining in Gabon and Niger. Due to technical problems, the film was stopped after half an hour and replaced by a debate with a selection of about 30 members of the community. Workers where enquiring about the influence of the duration of work in a mine on their health, safety standards, and different dosimetry methodologies used to monitor their exposure to radiation. They complained that the results of their individual dosimetry where not communicated to them. CRIIRAD later raised the issue at meetings in Lilongwe with the Director of mines and the Deputy Director of EIA at the Ministry of Environment (see **Section 2.4**).

Figs.15-16

CRIIRAD and CFJ are organizing training and communication activities with the Kayelekera Community

Source: CRIIRAD, May 2012

2.4 Meeting with official institutions in Karonga and Lilongwe (May 2012)

While in Kayelekera, the team went to Paladin mine gate and asked for a meeting with representatives of the company. The response was negative.

CFJ and CRIIRAD could meet the inspector of Fisheries in Karonga. He said he was never given inspection report or any reports by either Paladin or the competent governmental department. He mentioned two incidents with trucks transporting sulphur. One took place near the bridge crossing the Sere River at Kayelekera and abnormal death of fishes was reported but the connection with the spill could not be proven. Another took place in another place. He also indicated that following an anonymous declaration, Paladin was fined for illegal burning of some types of waste, but no detail was given to CRIIRAD.

With the efficient help of CFJ director, M Reinford Mwangonde, CRIIRAD could meet government bodies in Lilongwe. At each meeting, M. Chareyron (CRIIRAD) explained the structure and goals of CRIIRAD, the methodology applied during the 4 days spent in Kayelekera and asked for copies of Paladin environmental reports.

During the meeting with the Director of mines: M. Charles Kaprio, CRIIRAD asked a copy of the Paladin environmental reports and required permission to organise on site measurements inside the mine in case of a new mission to Kayelekera. CRIIRAD also asked for the transmission of results of individual dosimetry to the

concerned workers (see section 7 / recommendations). The director of mines gave support to CRIIRAD request of visiting the mine in the following years and suggested to CFJ to send a written document for transmission of the reports.

CFJ and CRIIRAD could also meet the Director and deputy Director of Environmental Impact Assessments at the ministry of the environment. The department would wish to conduct a quarterly inspection at Paladin mine but due to the lack of resources, it is not possible. Monitoring equipment has recently been provided to the government of Malawi by the IAEA but has not been used yet. In order to get a copy of Paladin environmental reports it is necessary to ask permission to Paladin because the documents belong to the company. CFJ should prepare the appropriate letters. CRIIRAD asked if monitoring of water sampled in the boreholes located downstream the seepage dam showed any indication of a seepage and if the grout curtain designed to limit the risk of seepage was actually in place. The answer was that no evidence of seepage had been reported to the ministry and no information about any grout curtain was available.

2.5 Sampling activities at Kayelekera

During the 4 days mission to Kayelekera, CRIIRAD team organized on site radiation monitoring and sampling activities with CFJ and the community.

These activities included the monitoring of external irradiation (gamma radiation), the sampling of underground and surface water, top soil and sediments, and the monitoring of radon in the air.

The results are given in the appropriate sections below.

CRIIRAD and CFJ sampling activities with the community in Kayelekera (May 2012)

Figs 17-18

Monitoring of gamma radiation in Kayelekera and Nkhachira

Source: CRIIRAD, May 2012

Figs. 19-20

Discussion with the chief of Kayelera village at Nkhachira (left: dry borehole ; right : presentation of a radon passive detector)

Source: CRIIRAD, May 2012

Figs. 21-22

Sampling of top soil (left) and discussion about the location of the main streams (right)

Source: CRIIRAD, May 2012

3 Results of independent monitoring of underground water

3.1 Sampling of underground water

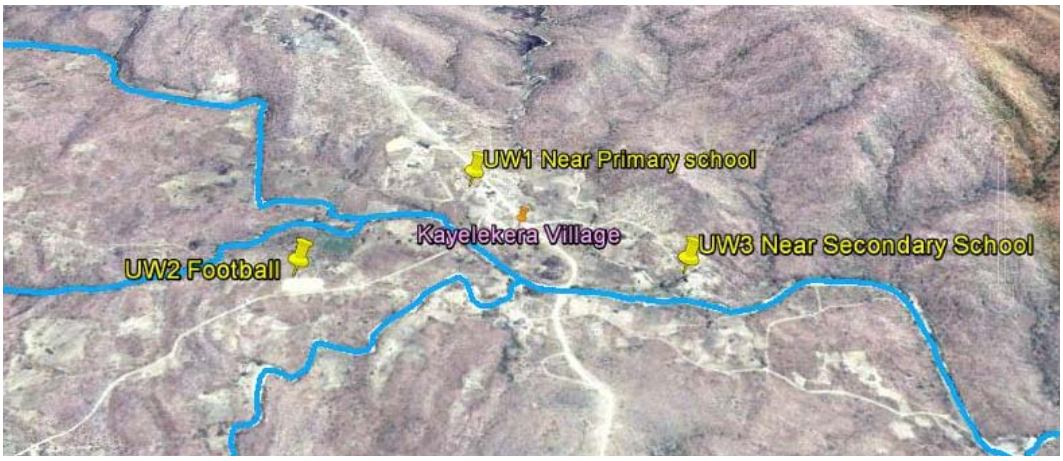
Underground water used for human consumption was sampled in Kayelekera village by CRIIRAD and CFJ at 3 locations chosen taking into consideration the wishes of the community and the technical interest of the samples. The sampling is not comprehensive as other boreholes are being used in the village.

Sampling locations are plotted in **Figs. 23** and **24**.

Fig. 23

Location of underground water samples / general view

Source: GoogleEarth view September 2008



The samples are including the two boreholes identified during the hydrocensus and mentioned in Paladin Environmental Impact Assessment Report published in September 2006:

- one artesian borehole near the secondary school (sample UW3, borehole HBH2, Fig. 26), it is associated with the basement fault (2006 EIA, page 6-93).
- one borehole equipped with a handpump located near the primary school (sample UW1 on the left bank of the Sere river, borehole HBH1, Fig. 24). According to the 2006 EIA report, the depth to groundwater was 26 m and 55 m respectively in June 17th and June 7th (page 6-97).

Both boreholes are located more than 1.7 km to the north / north-west of the uranium mine. According to the 2006 report, they provide potable water to about 25 and 50 people respectively.

Another borehole that was equipped with a handpump by Paladin Africa in August 2007 has been sampled by CRIIRAD. It is located close to the football ground (sample UW2, on the right bank of the Sere River, Fig. 25). CRIIRAD has no information about the depth to groundwater.

All water samples were collected in a 1 litre plastic container with special obturator and screwed cap. No air was left between the surface of the liquid in the plastic vial and the obturator in order to lower the risk of transfer of dissolved radon.

Figs. 24-25

Sampling of underground water UW1 and UW2 at Kayelekera

Source: CRIIRAD, May 2012

Fig. 26

Sampling of underground water UW3, artesian borehole, at Kayelekera

Source: CRIIRAD, May 2012

Fig. 27

Location of underground water samples / general view

Source: GoogleEarth view September 2008

3.2 Radiation protection standards applied to drinking water

In the case of water used for human consumption; the dose limit recommended by the WHO (World Health Organization) is set to 100 microSievert per year (0.1 milliSievert per year), but radon 222 dissolved in the water is not taken into consideration for the evaluation of this dose.

WHO guidelines for radiological aspects are the following : Lead 210 and polonium 210 : 0.1 Bq/l ; Radium 226, Uranium 234 and uranium 235 : 1 Bq/l ; Uranium 238 : 10 Bq/l. If several radionuclides are present in the water, the values have to be lowered accordingly taking into consideration the dose limit of 0.1 mSv.

In fact, the WHO 2004, 2006 and 2008 reports recommended to monitor separately dissolved radon in the water and to take corrective actions if the activity was above 100 Bq/l. WHO 2011 recommendations still recommend to monitor radon in the water and take appropriate measures if the values are too high but gives no more limit. Only recently, a European Directive as set a limit of 100 Bq/l for radon 222 activity in drinkable water. CRIIRAD recommended not to exceed 10 Bq/l and the European Parliament agreed to set a limit of 20 Bq/l, but its position was only advisory and the final decision of the Commission was 100 Bq/l (EURATOM 2013/51). In France, as suggested by WHO recommendations, in the case of water used for human consumption, gross alpha and gross beta activities have to be monitored.

If gross alpha activity is below 0.1 Bq/l and gross beta activity is below 1 Bq/l, it is assumed that the annual dose limit will remain below 0.1 mSv/year which is the recommended limit. If these limits are exceeded, it is required to monitor individually different radionuclides in order to know their activity in the water and to calculate the annual dose induced by the consumption of the water.

CRIIRAD pointed out several problems with this methodology: dissolved radon 222 is not included in the monitoring while its activity may be quite significant (especially in underground water samples); the limit for gross beta activity is too high in case of the presence of lead 210 (a very radiotoxic natural beta emitter),

the dose standards are calculated for adults and do not take into consideration the higher radiosensitivity of children, etc...

3.3 Analytical strategy

Water samples have been analysed at the CRIIRAD laboratory in France (measurements performed by HpGe gamma spectrometry) in order to monitor main artificial and natural radionuclides (radon 222, radium 226, etc...). Due to technical constraints, the detection limit and analytical uncertainties are higher than usual because CRIIRAD could bring only one litre of water back to France while usually such analysis are performed on a 10 litres sample.

Uranium has been monitored by the LDA 26 laboratory (France) and gross alpha and gross beta activities by the Eichrom laboratories (France).

The results are plotted in **Annex 1** (table A1).

In addition, a selection of chemicals: 15 anions and cations and 26 metals have been monitored by LDA 26 (see **Annex 1**, tables B1 and C1).

Regarding the concentrations of the main anions, cations and metals, it should be noted that orthophosphates are detected in sample UW2 (0.04 mg/l) and that the concentration of iron in sample UW1 (310 µg/l) is slightly above WHO standard of 300 µg/l.

3.4 Radiological characteristics of the underground water

Main results are plotted in **table 1** below.

In sample UW2 (handpump close to the football ground), both parameters (alpha < 0.05 Bq/l and beta < 0.03 Bq/l) are below the required standards. Radon 222 activity is below the detection limit (< 12 Bq/l).

Sample Code (on site)	UW1	UW2	UW3
CRIIRAD Lab Code	280512A6	280512A7	280512A8
Location	Drinkable water from a borehole at Kayelekera	Drinkable water from a borehole at Kayelekera	Drinkable water from a borehole at Kayelekera
Description	Hand pump close to Primary school	Hand pump close to football ground	Artesian borehole close to secondary school
GPS coordinates	S9 57.973	S9 58.211	S9 58.196
GPS coordinates	E33 40.939	E33 40.650	E33 41.311
Sampling time (local)	22.5.12 13:30	22.5.12 14:15	22.5.12 15:45
Global radiological parameters (b)			
Gross alpha activity (Bq/l)	0,14 ± 0,04	< 0,05	0,30 ± 0,10
Gross bêta activity (Bq/l)	0,20 ± 0,03	< 0,03	0,56 ± 0,08
Potassium (mg/l)	2,27 ± 0,10	1,12 ± 0,05	2,08 ± 0,09
Potassium 40 (Bq/l), calculated	0,063 ± 0,003	0,031 ± 0,001	0,057 ± 0,002
Residual Gross bêta activity (Bq/l)	0,14 ± 0,03	< 0,03	0,50 ± 0,08
Uranium (a)			
Uranium 238 (µg/l)	0,3	0,76	0,18
Calc. U238 activity (Bq/l)	0,003	0,010	0,002
Uranium 235 (% uranium 238)	0,74	0,72	nd
Radon 222 (c')			
Radon 222 (Bq/l)	23 ± 11	< 12	89 ± 23
Gamma emitting natural radionuclides (d)			
Th 234 (Bq/l)	< 3,3	< 4,2	< 1,5
Ra 226 (Bq/l)	< 0,30	< 0,32	detected < 0,7
Pb 210 (Bq/l)	< 1,4	< 1,6	< 1,6
U 235 (Bq/l)	< 1,3	< 1,4	< 0,7
Pb 212 (Bq/l)	< 0,16	< 0,17	< 0,18
K40 (Bq/l)	< 2,4	< 2,6	< 4,2
Gamma emitting artificial radionuclides (e)			
Gamma emitting artificial nuclides (Bq/l)	< DL	< DL	< DL

Table 1

Radiological characteristics of underground water samples

Source: CRIIRAD

In samples UW1 (handpump close to the Primary school) and UW3 (artesian borehole):

- The gross alpha activity is above the limit of 0.1 Bq/l (0.14 Bq/l and 0.3 Bq/l respectively). In this case, more detailed analysis are required in order to determine which alpha emitters are involved (it could be radioactive isotopes of uranium, radium, thorium, polonium, etc...).
- Dissolved radon 222 is detected with activities of 23 Bq/l (UW1) and 89 Bq/l (UW3) which are not negligible even if below the limit of 100 Bq/l recommended by a recent European directive.

Uranium concentrations in both samples are low (0.3 and 0.18 µg/l respectively) and well below the new WHO standard of 30 µg/l.

But, in the case of the artesian borehole UW3, the main contributor to the alpha activity is very probably radium 226 as suggested by the analysis performed at the CRIIRAD laboratory. Radium 226 is detected, but due to the low amount of liquid available, the result is below the detection limit (< 0.7 Bq/l) and the activity cannot be accurately evaluated.

It should be noted that radium 226 activity mentioned in Paladin EIA (year 2006, page 6-134) was 0.52 Bq/l in the sample called “artesian borehole” which is very probably UW3 (taking into consideration the map provided in the report).

These results suggest that the amount of radium 226 in the water of the artesian borehole is of natural origin as the monitoring was done prior to the commissioning of the mine.

Taking into consideration the activity of radium 226 only, the annual dose for an adult drinking 2 liters of water per day would be above the value of 0.1 mSv/year recommended by the WHO.

In order to calculate the actual dose, it is necessary to monitor other radionuclides including lead 210. Unfortunately, due to the limitation on the amount of water, the monitoring performed by CRIIRAD in May 2012 gives a detection limit which is too high for lead 210 (< 1.6 Bq/l).

Paladin EIA main report (2006) does not give results for the monitoring of Lead 210 in groundwater. The table showed on page 6-134 gives results for polonium 210 with activities of 3.07 mBq/l and 2.99 mBq/l in samples called production borehole and artesian borehole.

An appendix to the report dated 10 August 2006 and provided by GCS LTD gives results of Lead 210, gross alpha activity and gross bêta activity. But the unit is not mentioned for lead 210 whose activities are 3.07 and 2.99 respectively for samples HBH1 and HBH2. These figures are probably expressed as mBq/l and are equal to the figures reported as polonium 210 activities in the main report.

It is shocking to read that according to the GCS report, the dose calculated with a water intake of 730 liters per year is 1.51 microSievert per year for the artesian borehole (HBH2).

Indeed, this dose is estimated using the activity of lead 210 and bismuth 210 only. When using the monitored activities of uranium 238, uranium 234, thorium 230 and radium 226 published in the main EIA report, CRIIRAD calculates a dose of 114 microSievert per year or 0.114 milliSievert per year (above the 0.1 mSv limit). When adding the activity of dissolved radon 222 monitored by CRIIRAD, the dose reaches 0.76 milliSievert per year. The evaluation of doses to the consumer of the water is therefore strongly underestimated in Paladin EIA.

Recommendations

The measurements performed on three underground water samples collected by CRIIRAD in May 2012 in the village of Kayelekera show that:

- The radiological characteristics of sample UW2 collected near the football ground are below the limits given by the WHO.
- In the case of sample UW1 collected near the primary school, additional monitoring would be necessary taking into consideration the fact that the gross alpha activity is slightly above the limit of 0.1 Bq/l. The consumption of 730 liters of water per year would induce a dose of 0.014 mSv/year, taking into consideration the activity of uranium 238 daughter products (based on the results of EIA 2006 report) and 0.18 mSv/year when including radon 222 (CRIIRAD monitoring).
- The radiological characteristics of the water of the artesian borehole (sample UW3) induce a dose to the consumer which is above 0.1 milliSievert per year. The consumption of 730 liters of water per year would induce a dose of 0.11 mSv/year, taking into consideration the activity of uranium 238 daughter products (based on the results of EIA 2006 report) and 0.76 mSv/year when including radon 222 (CRIIRAD monitoring).

Additional monitoring of underground water samples would be necessary to confirm these results and study their variability over time.

For this purpose, it would be very useful to obtain copies of the monitoring campaigns performed by Paladin Africa.

Unfortunately, Paladin 2012 and 2013 Sustainability reports which are available on Paladin website give no information about the results of the environmental monitoring performed in Kayelekera. More detailed reports are probably prepared and submitted to the competent authorities of the government of Malawi.

If a comprehensive monitoring is not performed, the authorities should impose one to the mining company. It should include the monitoring of dissolved radon, gross alpha and gross beta activity, main anions and cations, metals and organic pollutants. Depending on the results, more detailed radiological evaluations should be performed including uranium isotopes, radium 226, lead 210, polonium 210, etc.

4 Results of independent monitoring of surface water

4.1 Sampling of surface water

The Chapwasha River is flowing on the western side of the uranium mine in direction of the north and reaches the Sere River in the village of Kayelekera. This river may be potentially impacted by the uranium mine and by the coal mine located on its catchment.

Then, downstream of the village of Kayelekera, the Sere River flows on the eastern side of the uranium mine where it may be submitted to water potentially leaking from the uranium mine. There are various sources of contamination including the open pit (Champhanji stream), the dams built to collect contaminated waters, and Tailings Storage Facilities (TSF) (Chimbembe and Kantchindu streams). In case of leakages from the open pit and TSF, the most vulnerable river is therefore probably the Sere River. The Sere River will then meet the North Rukuru River that is flowing into lake Malawi at about 36 km from the uranium mine.

Five samples of surface water have been collected by CRIIRAD and CFJ between May 20th and 22nd of 2012:

- SW1: in the Sere river upstream of the confluence with the Chapwasha river and upstream of the uranium mine.
- SW2: in the Chapwasha river close to its connection with the Sere river.
- SW3: in the Sere river, about 1.6 km downstream of the Champhanji stream and the open pit.
- SW4: in the Champhanji stream below the open pit.
- SW5: in the North-Rukuru river at about 12 km downstream of the mine.

Unfortunately, due to time constraints, to the difficulty of accessing the area by walking and to the problems of localization[9], it was not possible to reach the Kanchindu stream immediately downstream the TSF A (location SWX on Fig. 30). Water sample SW3 (Sere river) is therefore not under the influence of the TSF A but it may be impacted by leakages from the open pit and dams built to store contaminated water.

Sampling locations are plotted in **Figs. 30** and **31**.

Figs. 28-29

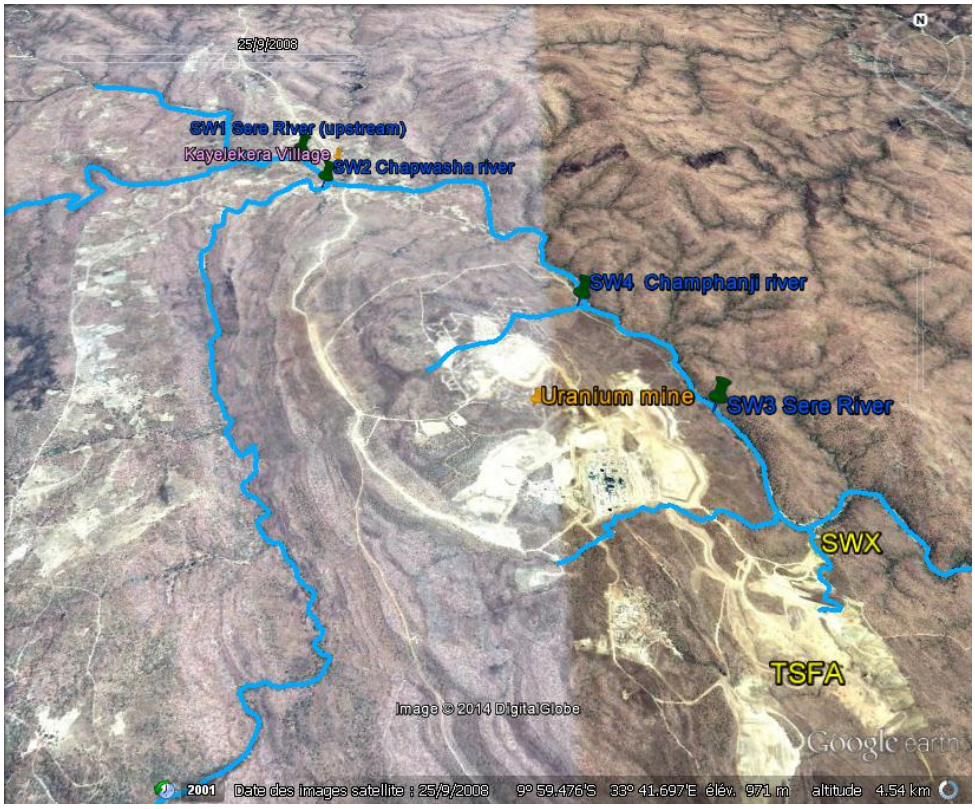
Sampling in the Sere river Valley

Source: CRIIRAD, May 2012

Fig. 30

Location of surface water samples / Zoom near the uranium mine

Source: GoogleEarth view of September 2008



[9] It should be noted that Paladin EIA gives different names to the rivers in different chapters which is confusing. Even the villagers and Paladin sampling team that we met in Kayelekera village could not give us coherent denomination of some of the rivers.

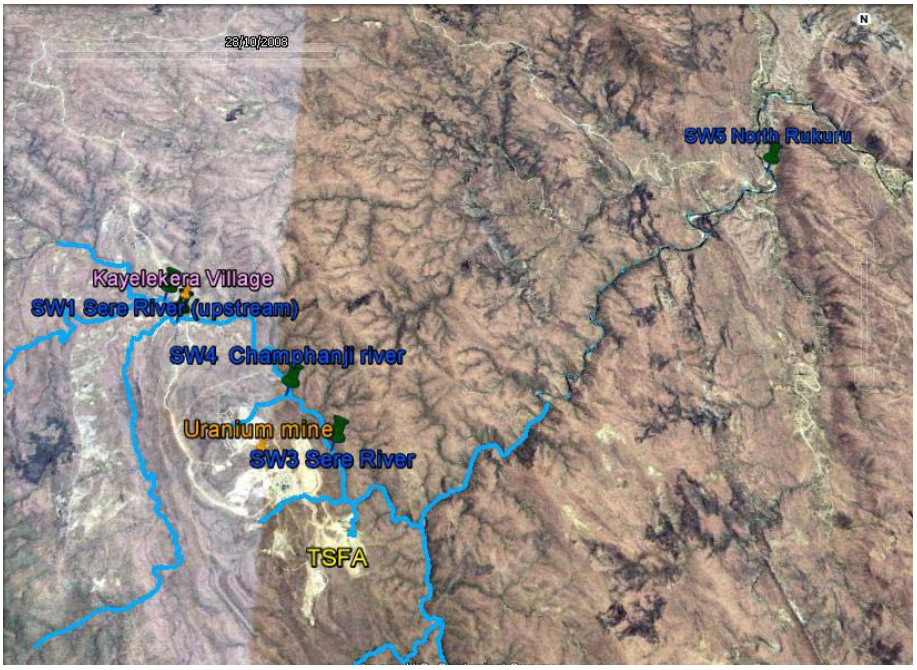


Fig. 31

General view of surface water samples, including sample SW5 (North Rukuru river downstream the confluence with the Sere river)

Source: GoogleEarth view of September 2008

All water samples were collected in a 1 liter plastic container with special obturator and screwed cap. No air was left between the surface of the liquid in the plastic vial and the obturator.

4.2 Analytical strategy

The samples of surface water have been analysed at the CRIIRAD laboratory in France (measurements performed by HpGe gamma spectrometry) in order to monitor main artificial and natural radionuclides (radon 222, radium 226, thorium 234, etc...). Uranium has been monitored by the LDA 26 laboratory in France. The results are plotted in **Annex 1** (last columns of table A1). Due to funding limitation, gross alpha and gross beta activities have not been monitored.

In addition, a selection of chemicals (15 anions and cations and 26 metals) have been monitored by LDA 26 (see **Annex 1**, last columns of tables B1 and C1).

4.3 Results of independent monitoring of surface water

The radiological characteristics of the samples of surface water are given in **table 2**.

Uranium

As illustrated by Fig. 32 below, the concentration of uranium is quite low in the Sere river upstream of the uranium mine (SW1: 0.22 µg/l) and in the Chapwasha river (SW2 : 0.47 µg/l).

But it is very high in the Champhanji stream flowing under the potential influence of the open pit (5 230 µg/l which is equivalent to 65 Bq/l for uranium 238). For comparison, the WHO recommended limit for uranium in drinkable water is 30 µg/l. In the case of France, the discharge limit for effluents from uranium mines is 1 800 µg/l. This limit applies to the effluent prior to dilution in the river. Moreover, it is too high a limit because it was set before the establishment of the new recommendations of the International Commission on Radiological Protection (ICRP 60 in 1990).

Impact is detected in the Sere river about 1.6 km downstream the confluence with the Champhanji river (SW3 : 42.8 µg/l).

This impact is detected in the Sere river about 1.6 km downstream the confluence with the Champhanji river (SW3 : 42.8 µg/l).

Further downstream, the impact is much lower (1.45 µg/l in sample SW5 in the North Rukuru river) but the uranium concentration is still higher than upstream the uranium mine.

Fig. 32

Uranium concentration (µg/l) in the rivers near Kayelekera uranium mine

Source: CRIIRAD, May 2012

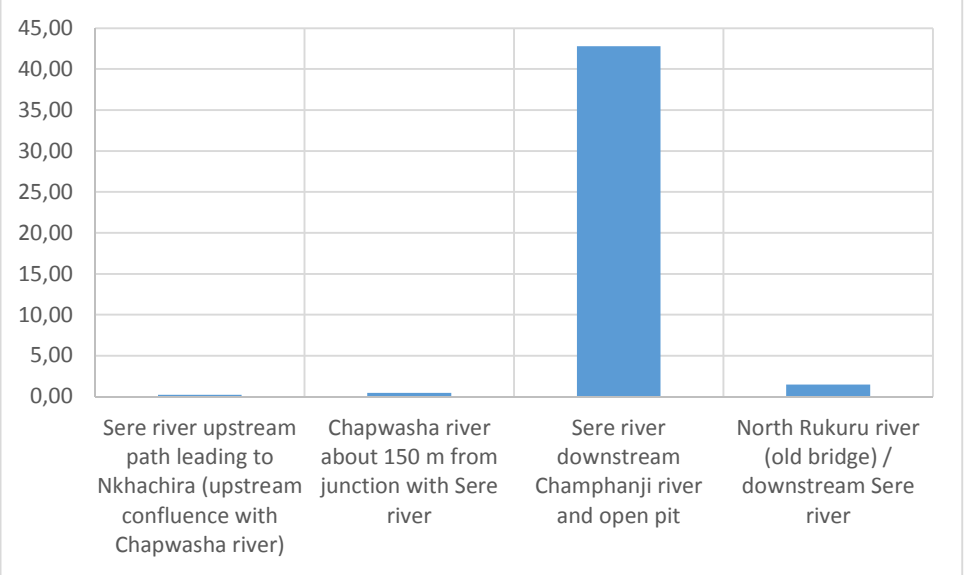


Table 2 Radiological characteristics of surface water samples

Source: CRIIRAD

Sample Code (on site)	SW1	SW2	SW4	SW3	SW5
CRIIRAD Lab Code	280512A1	280512A2	280512A4	280512A3	280512A5
Location	Sere river upstream path leading to Nkhachira (upstream confluence with Chapwasha river)	Chapwasha river about 150 m from junction with Sere river	"Champhanji" river downstream open pit	Sere river downstream Champhanji river and open pit	North Rukuru river (old bridge) / downstream Sere river
Description	Surface water (right bank)	Surface water (left bank)	Surface water of a stream	Surface water (right bank)	Surface water
GPS coordinates	S9 58.052	S9 58.255	S9 58.942	S9 59.421	S9 56.620
GPS coordinates	E33 40.866	E33 41.001	E33 42.014	E33 42.422	E33 46.503
Sampling time (local)	20.5.12 14:00	20.5.12 14:40	21.5.12 15:00	21.5.12 12:40	22.5.12 17:20
Uranium (a)					
Uranium 238 (µg/l)	0,22	0,47	**5.230**	**42,8**	1,45
Calc. U238 activity (Bq/l)	0,003	0,006	65,38	0,535	0,02
Uranium 235 (% uranium 238)	0,68	0,70	0,78	0,68	0,72
Radon 222 (c')					
Radon 222 (Bq/l)	< 10	< 7	42 ± 17	< 30	< 25
Gamma emitting natural radionuclides (d)					
Th 234 (Bq/l)	< 9	< 3,5	63 ± 9	< 3,1	< 1,4
Ra 226 (Bq/l)	< 0,30	< 0,31	1,45 ± 0,48	< 0,30	< 0,38
Pb 210 (Bq/l)	< 1,5	< 1,4	< 1,5	< 1,4	< 1,4
U 235 (Bq/l)	< 1,4	< 1,4	5,9 ± 2,1	< 1,4	< 0,8
Pb 212 (Bq/l)	< 0,17	< 0,20	< 0,19	< 0,21	< 0,23
K40 (Bq/l)	< 2,5	< 2,4	< 2,4	< 2,5	< 4,5
Gamma emitting artificial radionuclides (e)					
Gamma emitting artificial nuclides (Bq/l)	< DL	< DL	< DL	< DL	< DL

Other radionuclides

The water of the Champhanji stream carries other radioactive substances associated to the uranium decay chain. CRIIRAD monitored thorium 234 (63 ± 9 Bq/l), radium 226 (1.45 ± 0.48 Bq/l) and radon 222 (42 ± 17 Bq/l). The activities of these radionuclides were below the detection limit in the Sere river upstream (SW1) and downstream (SW3) the confluence with the Champhanji stream.

It should be noted that the water of the Sere river may be used for human consumption including for Paladin's personal. The monitoring performed by CRIIRAD in May 2012 show that the amount of uranium in some sections of the river is above WHO guideline of 30 µg/l. The results of the 1990 EIA also show high activities of radium 226 and lead 210 (a very radiotoxic substance) in the Sere river water during the dry season (see Fig. 33).

Chemicals

The concentrations of other chemicals monitored in the Champhanji stream are more than 10 times higher than the values monitored in samples SW1 (Sere river upstream) and SW2.

This is the case for:

- Arsenic (1.59 µg/l)
- Boron (8.98 µg/l)
- Baryum (452 µg/l)
- Cadmium (0.03 µg/l)
- Lithium (25.5 µg/l)
- Molybdenum (5.59 µg/l)
- Selenium (0.3 µg/l)
- Sulfates (62 mg/l).
- Uranium (5 230 µg/l which is equivalent to 65 Bq/l).

Only the concentration of uranium is exceeding the WHO standard recommended for drinkable water (30 µg/l).

Clear impact of the uranium mine

The high level of uranium detected in the Champhanji stream may be of natural origin or may be due to the mining activities.

Indeed, the monitoring performed in the 1990[10] EIA (see **Fig. 33**), before the commissioning of the mine, showed that uranium 238 activity in the Champhanji stream was between 0.05-0.24 Bq/l (wet season) and 1.4 Bq/l (dry season). The

[10] The results of radiation monitoring of surface water performed in the course of the 2006 sampling programme were not included in the 2006 EIA report. But the results of chemical analysis are reported.

activity monitored by CRIIRAD in May 2012 is much higher (65 Bq/l) which suggests an impact from the mining activities.

The impact of the mining activities is also probably the origin of the high concentration of sulfates monitored in May 2012 in the Champhanji stream (62 mg/l).

This result is much higher than

- the values monitored in the Sere river upstream (below detection limit) and in the Chapwasha river (5.7 mg/l)
- the values monitored by Paladin in May 2006 in the Champhanji stream (19 mg/l).

Paladin 2006 EIA report (page ES-12), acknowledges that "the salts that could be mobilised in the waste rock leachate include calcium and sulphates. Manganese is the dominant metal that could be mobilised".

Indeed, the concentration of calcium and manganese in the Champhanji stream (49 mg/l and 6 µg/l) are higher than in the Sere river upstream (15 mg/l and 2.36 µg/l), but the highest impact concerns uranium.

These results show that it is necessary to get detailed information from Paladin Africa about the strategy used to limit the dispersion of radioactive materials from the open pit, waste rock dumps and TSF.

Situation of the North Rukuru River

In the North Rukuru river, the radiological and chemical monitoring performed by CRIIRAD in May 2012 shows no specific contamination of the water.

The only parameter whose concentration is at least 3 times above the values monitored upstream (i.e in the Sere river upstream from the mine or in the Chapwasha river) is uranium 238. But its activity (1,45 µg/l or 0.02 Bq/l) is comprised in the interval observed prior to the commissioning of the mine (between 0.005 and 0.12 Bq/l according to the 1990 EIA report, see **Fig. 33** below).

Radionuclide concentrations in river waters – dry season

Concentrations in stream water (mBq/l)				
River	U-238	Ra-226	Pb-210	Th-232
Sere	40-260	3-960	100-820	< 1
Champhanji	1 400	3 000-11 000	900-3 000	< 1
North Rukuru	5-120	< 30	< 50	~ 1

Radionuclide concentrations in river waters – wet season

Concentrations in stream water (mBq/l)				
River	U-238	Ra-226	Pb-210	Th-232
Sere	<5 to 40	<100	< 100	< 1-9
Champhanji	50-240	<100	< 100	5-10
North Rukuru	5 to 70	<100	< 100	< 2-9

Note: '<' denotes values below the limit of detection

Fig. 33

Results of monitoring of surface water during the dry and wet seasons according to the previous 1990 EIA

Source: Paladin EIA 2006, page 6-132

5 Results of independent monitoring of soil and sediments

5.1 Analytical methodology

Twelve samples of soil and sediments have been collected by CRIIRAD and CFJ, in May 2012, in the surroundings of the Kayelekera uranium mine and Nkhachira coal mine.

At each location, about 250 cc of material (surface sediments or soil) have been collected (about 1 to 2 cm depth) using a shovel and immediately packed in a 250 cc labelled plastic pot with screwed cap.

Sampling location (including GPS coordinates), sampling time and sample description are given in **Appendix 2** along with:

- the dry/wet ratio of the material (%). This ratio is between 69 and 75 % for the sediments sampled under water and above 92 % for the other samples.
- the values of the gamma flux (counts per second : c/s) monitored with a DG5 scintillometer at the surface of the soil (or the bank of the river in the case of sampling of wet sediments) and one meter above ground.

At the CRIIRAD laboratory, the flux of gamma radiation has been monitored on each sample using another type of scintillometer (SPP2-Saphymo). These results are given in Appendix 3 (results in counts per second : c/s). Then the samples have been dried at 105°C, sieved below 2 mm, homogenized and packed in Petri dishes and counted on a HpGe gamma spectrometry detector. The analysis took place after at least 21 days after packing in order to let radium 226 recover its equilibrium with lead 214 and bismuth 214, whose gamma lines have been used to monitor the activity of radium 226. Details about counting are given in **Appendix 3**.

5.2 General comments

Results show that thorium 232 has to be taken into consideration when assessing the natural exposure of the local population to ionizing radiation.

The radiological characteristics of the solid samples are presented in table 3 to 5 below. No gamma emitting artificial radionuclides have been detected (as an example, the detection limit is given for caesium 137).

The earth crust naturally contains the following radionuclides: potassium 40, and 3 radionuclides associated with their own decay chain: uranium 238, uranium 235, and thorium 232.

Natural radionuclides of the uranium 238 decay chain (thorium 234, thorium 230, radium 226, lead 210) have been detected in most of the samples. The typical activity of uranium 238 and its decay products in the earth crust is about 40 Bq/kg. But it varies depending on the geology of the area. According to Paladin 2006 EIA report, the mean activity of uranium 238 in the uranium ore is about 8 500 Bq/kg.

In the samples collected by CRIIRAD and CFJ, the activity of uranium 238 (thorium 234) varies between 48 Bq/kg (coal) and 1 860 Bq/kg (radioactive material SD5 collected in a disturbed area on the eastern slope of Paladin mine lease).

Natural uranium 238 is necessarily associated with uranium 235. The natural activity of uranium 235 is equal to uranium 238 activity divided by 21.6. The activity of uranium 235 exceeded the detection limit in only one sample (SD5), with an activity coherent with uranium 238 activity (taking into consideration the uncertainties of the measurements).

The typical activity of thorium 232 and its decay products in the earth crust is about 40 Bq/kg. In the thorium 232 decay chain, CRIIRAD monitored actinium 228, lead 212 and thallium 208. The activity of actinium 228 varies between 25 Bq/kg (sample SD7 of dried sediments from a stream on the north-eastern slope of Paladin mine) and 2 160 Bq/kg (sample TS4 : natural sand collected on the path leading to Nkhachira village). In the area of Nkhachira, sample TS2, collected at the entrance of the coal mine, also has quite a high activity (430 Bq/kg). These results show that thorium 232 has to be taken into consideration when assessing the natural exposure of the local population to ionizing radiation.

The typical activity of potassium 40 in the earth crust is about 400 Bq/kg. Its activity in the samples collected by CRIIRAD varies from 430 Bq/kg (dried sediments SD7 from a stream on the north-eastern slope of Paladin mine) to 1 280 Bq/kg (sample TS4: natural sand collected on the path leading to Nkhachira village).

5.3 Top soil in the villages

Two samples of top soil have been collected in the village of Kayelekera (TS 1) and Nkachira (TS 3) in order to look for abnormal levels of uranium 238 or its decay products that may indicate a deposition of radioactive dust due to blasting in the open pit.

The samples were collected in front of houses at places were the dust from regular cleaning is deposited (see **Figs. 34** and **35** below).

The two locations were selected after a discussion with the community taking into consideration their knowledge of the wind direction and observation of the trajectory of the clouds of dust produced during blasting activities. The second criteria was to have one sample in Kayelekera and another one in Nkachira.

The flux of gamma radiation at the surface of the ground were 130 c/s and 190 c/s respectively (DG5 scintillometer).

- TS1 is located about 2.4 km North / North West from the uranium mine.
- TS3 is located about 2 km west from the uranium mine.

Sampling locations are plotted in **Figs. 36** and **37** (based on satellite images taken in 2008 and 2013 respectively).

Figs. 34-35

Sampling of top soil TS1 and TS3

Source: CRIIRAD, May 2012

The results of the radiological analysis are given in table 3, page 30.

In both samples, the activities of uranium 238 and its decay products are between 33 Bq/kg and 51 Bq/kg.

These results are comparable to the mean activity of the earth crust and do not indicate enhanced activity that could be connected to the deposition of radioactive dust from the mine.

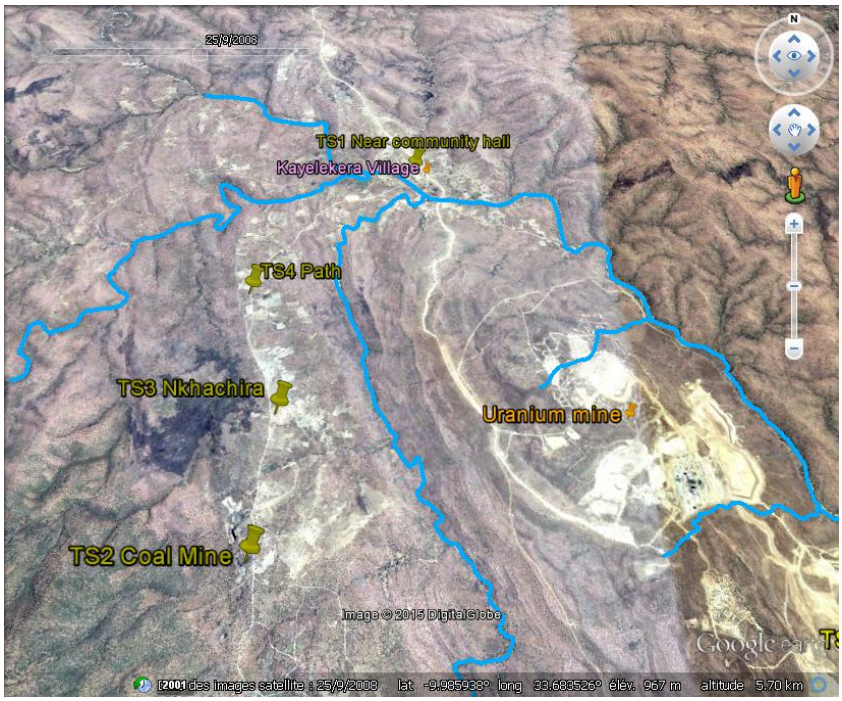


Fig. 36

Location of coal mine, uranium mine and soil samples TS1, TS2, TS3, TS4

Source: GoogleEarth, 2008

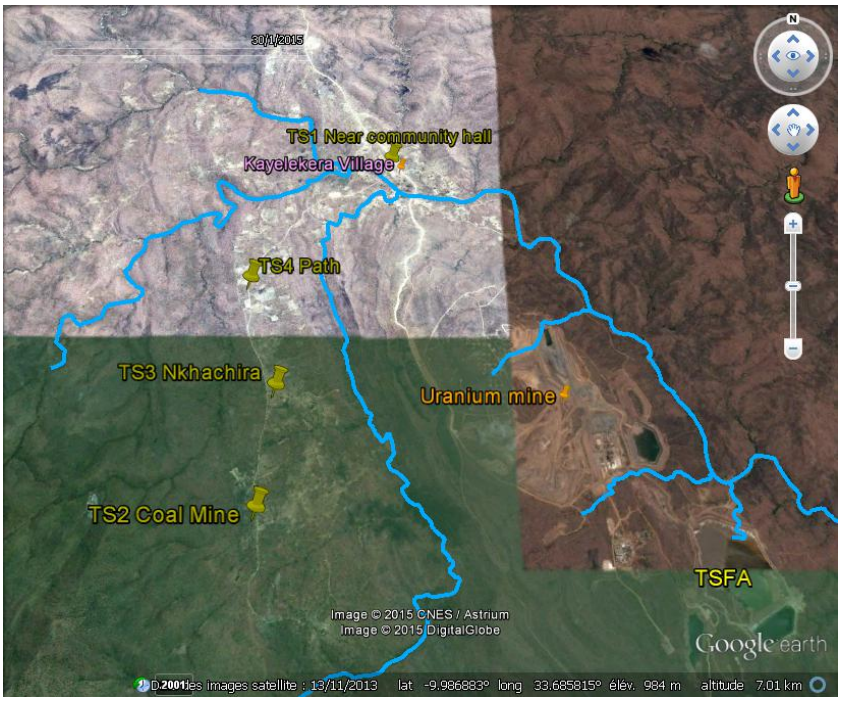


Fig. 37

Location of coal mine, uranium mine and soil samples TS1, TS2, TS3, TS4

Source: GoogleEarth, 2013

Table 3 Analysis of top soil samples TS1 to TS4 collected in May 2012 (gamma spectrometry at CRIIRAD laboratory)

Source: CRIIRAD

Code	Location	Description of sample	Uranium 238 (Thorium 234) (Bq/kg dry)*	Thorium 230 (Bq/kg dry)*	Radium 226 (Bq/kg dry)	Lead 210 (Bq/kg dry)*	U 235 (Bq/kg dry)	Thorium 232 decay chain : actinium 228 (Bq/kg dry)	K40 (Bq/kg dry)	Caesium 137 (Bq/kg dry)
TS 1	**Kayelekera village** / House of M Charles Sibale near Community Hall	Top soil including dust from regular cleaning of the surroundings of the house	48 ± 24	<80	50 ± 9	46 ± 17	<9	68 ± 14	600 ± 100	< 0.7
TS 3	In front of house of Kayelekera village's chief at **Nkhachira**	Top soil including dust from regular cleaning of the surroundings of the house	51 ± 23	<80	48 ± 8	33 ± 15	<8	68 ± 14	1180 ± 160	< 0.7
Coal	**Coal mine** inside mine pit (**Nkhachira**)	Freshly extracted coal	48 ± 30	<90	45 ± 9	< 33	<13	44 ± 13	160 ± 60	< 0,8
TS 2	Entrance to **coal mine at Nkhachira**	Radioactive top soil (sand) in a dry drainage area	159 ± 47	<180	149 ± 21	98 ± 30	<14	430 ± 60	1100 ± 160	< 1.0
TS 4	In the middle of the path **from Nkhachira to Kayelekera**	Top soil (dry sand) from the drainage of local sandstone.	600 ± 120	<1200	630 ± 70	410 ± 80	<35	2160 ± 240	1280 ± 180	< 2.2

* Due to the low energy of the gamma line used the activity may be underestimated (selfabsorption)

5.4 Soil collected near Nkachira coal mine

The Nkachira coal mine is located uphill on the left bank of the Chapwasha river, about 2 km west / south-west from the uranium mine.

Three samples of solid material have been collected near Nkachira:

- One sample of coal sampled directly in the coal mine pit (gamma flux of 150 c/s at the surface). Taking into consideration the risk of inhalation of dust during the combustion of coal, it was useful to check its radiological characteristics.
- A sample of sand in a dry drainage area at the entrance of the coal mine (TS2), where the flux of gamma radiation reached 390 c/s.
- A sample of top soil (dry sand), TS 4, collected in the middle of the path leading to Nkachira, at a place where sand accumulates due to the drainage of natural sandstone. The flux of gamma radiation reached 840 c/s at the surface of the ground. TS4 is located about 2.5 km west / north-west from the uranium mine.

The last two samples were collected considering that they could accumulate radioactive dust deposited on the soil and washed down by the rain.

Sampling locations are plotted in Figs. 36 and 37 (based on satellite images taken in 2008 and 2013 respectively).

The results of the radiological analysis are given in **table 3** above.

In the sample of coal, the activities of uranium 238 (48 Bq/kg) and its decay products are comparable to the mean activity of the earth crust (40 Bq/kg). The activity of thorium 232 (44 Bq/kg) is also comparable to the mean value in the earth crust (40 Bq/kg). But, in samples TS2 and TS4, the activity of uranium 238 is higher (159 Bq/kg and 600 Bq/kg respectively). The uranium 238 / radium 226 ratio is close to one. The activity of thorium 232 is also high (430 Bq/kg and 2 160 Bq/kg respectively).

It is difficult to determine the origin of the high uranium 238 and thorium 232 activities detected in top soil samples TS2 and TS4. These values may be of natural origin and have nothing to do with the impact of the uranium mine. A more comprehensive study would be necessary to conclude.

Figs. 38-39

Sampling and monitoring of gamma radiation in Nkhachira (coal mine)

Source: CRIIRAD, May 2012

Figs. 40-41

Sampling and monitoring of gamma radiation in Nkhachira (coal mine) Sample TS2

Source: CRIIRAD, May 2012

Figs. 42-43

Sampling and monitoring of gamma radiation in Nkhachira (path) Sample TS4.

Source: CRIIRAD, May 2012

5.5 Sediments and soil collected on the eastern slope of the uranium mine

CRIIRAD initial plan was to join the valley of the Kantchindu river where is located the tailings dump (TSFA) in order to collect sediments and water at the bottom of the valley (see Figs. 48 and 49).

The team decided to walk on a path from Kayelekera village on the right bank of the Sere river. As explained above, the team could not reach the Kantchindu valley, but on the way, the team could monitor gamma radiation and collect samples of soil-sediments on the eastern side of the uranium mine below the open pit and the dams built to contain raw water.

Four samples of solid material have been collected:

- SD7: fine grained sediment collected in a dry stream (see **Fig. 44** below), located about 200 meters north from the Champhanji river (gamma flux of 220 c/s at the surface).
- SD6: fine grained sediment collected under water, directly in the Champhanji stream (gamma flux of 650 c/s at the surface). This area is located about 400 m downstream the open pit (see **Fig. 45** below)
- SD4: sediment collected in a dry stream (see **Fig. 46** below), about 220 meters below the bottom of the dam designed to contain raw water. The flux of gamma radiation reached 550 c/s at the surface of the ground.
- SD5: dry soil at the bottom of a drainage area in a place showing signs of disturbance (see **Fig. 47** below) and elevated gamma radiation flux at the surface of the ground (950 c/s). In this area, the gamma flux reached 1 600 c/s. Sample SD5 is situated at about 330 m from the bottom of the dam designed to contain raw water.

Sampling locations are plotted in **Figs. 48-49** (general view) and **Figs. 50-51** (zoom).

Figs. 44-45

Sediments SD7 and SD6

Source: CRIIRAD, May 2012

Figs. 46-47

Sediments SD4 and SD5

Source: CRIIRAD, May 2012

Fig. 48

Samples collected on the eastern slope of the uranium mine (2008 satellite image)

Source: GoogleEarth-CRIIRAD

Fig. 49

Samples collected on the eastern slope of the uranium mine (2013 satellite image)

Source: GoogleEarth-CRIIRAD

The results of the radiological analysis are given in **table 4** below.

Table 4 Analysis of top soil and sediment samples collected in May 2012 on the eastern slope of the uranium mine (gamma spectrometry at CRIIRAD laboratory)

Source: CRIIRAD

Code	Location	Description of sample	Uranium 238 (Thorium 234) (Bq/kg dry)*	Thorium 230 (Bq/kg dry)*	Radium 226 (Bq/kg dry)	Lead 210 (Bq/kg dry)*	U 235 (Bq/kg dry)	Thorium 232 decay chain : actinium 228 (Bq/kg dry)	K40 (Bq/kg dry)	Caesium 137 (Bq/kg dry)
SD 7	Dry stream immediately north of "Champhanji " river , below the open pit	Fine grained sediment including clay (dry, 1 mm)	67 ± 29	<180	371 ± 46	79 ± 31	<15	25 ± 9	430 ± 90	< 1.2
SD 6	**"Champhanji" river** below the open pit	Fine grained sediment including clay (under water)	690 ± 110	<700	1660 ± 180	560 ± 80	<80	56 ± 12	720 ± 110	< 1.0
SD 4	Dry stream on the eastern slope of Paladin mine	Dry sediment (sand and clay)	250 ± 60	260±200	223 ± 30	274 ± 48	<41	56 ± 14	670 ± 110	< 0.8
SD 5	Disturbed and radioactive area on the eastern slope of Paladin mine lease	Dry material at the bottom of a drainage area (clay)	1860 ± 280	2700 ± 900	1980 ± 220	1660 ± 220	69 ± 42	74 ± 19	540 ± 110	< 1.6

* Due to the low energy of the gamma line used the activity may be underestimated (selfabsorption)

Sample SD5 has been collected in a place clearly disturbed by human activities showing that the high uranium content is connected to the mining activity.

In all four samples, the activities of thorium 232 and potassium 40 do not show elevated values.

But this is not the case for the uranium 238 decay chain.

The activity of radium 226 is much higher than uranium 238 activity in samples SD7 (371 Bq/kg / 67 Bq/kg) and SD6 (1 660 Bq/kg / 690 Bq/kg). These results suggest that the water flowing in these streams has a high radium 226 activity. This is coherent with the monitoring of surface water SW4 collected in the Champhanji river (1.45 Bq/l). The Champhanji river is known for a high radium 226 activity, but the impact of the uranium mine is clear when looking at the amount of uranium and sulfates in the water (see discussion page 23 to 26).

In samples SD4 and SD5, the uranium 238 decay chain is in equilibrium (uranium 238 to radium 226 ratio close to one) with a uranium 238 activity of 250 Bq/kg and 1 860 Bq/kg respectively.

Sample SD5 has been collected in a place clearly disturbed by human activities showing that the high uranium content is connected to the mining activity.

On the satellite picture of September 2008 (**Fig. 52**), no soil perturbation is visible while soil disturbances appear on October 2010 picture (**Fig. 53**).

It should be noted that this area is only 330 meter down the dam designed to contain raw water. One may imagine that spills from the dam may have induced a contamination of this area.

But another hypothesis, is that Paladin may have conducted drilling activities there during uranium prospection campaigns.

Paladin should be asked for additional information about the activities performed there.

Fig. 50

Samples collected on the eastern slope of the uranium mine (2013 satellite image), zoom

Source: GoogleEarth-CRIIRAD

Fig. 51

Samples collected on the eastern slope of the uranium mine (2013 satellite image), zoom.

Source: GoogleEarth-CRIIRAD

Fig. 52

Sample SD5 (disturbed land) collected on the eastern slope of the uranium mine (September 2008 satellite image) / No perturbation is seen on the picture.

Source: GoogleEarth-CRIIRAD

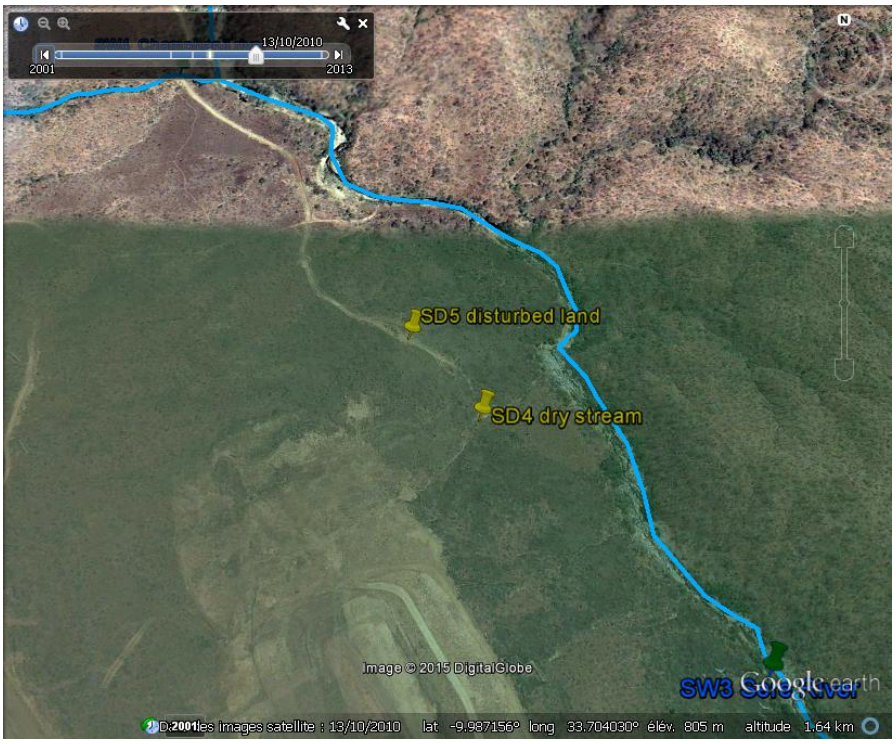


Fig. 53

Sample SD5 (disturbed land) collected on the eastern slope of the uranium mine (October 2010 satellite image) / soil perturbation is seen on the picture, no water in the reservoir

Source: GoogleEarth-CRIIRAD

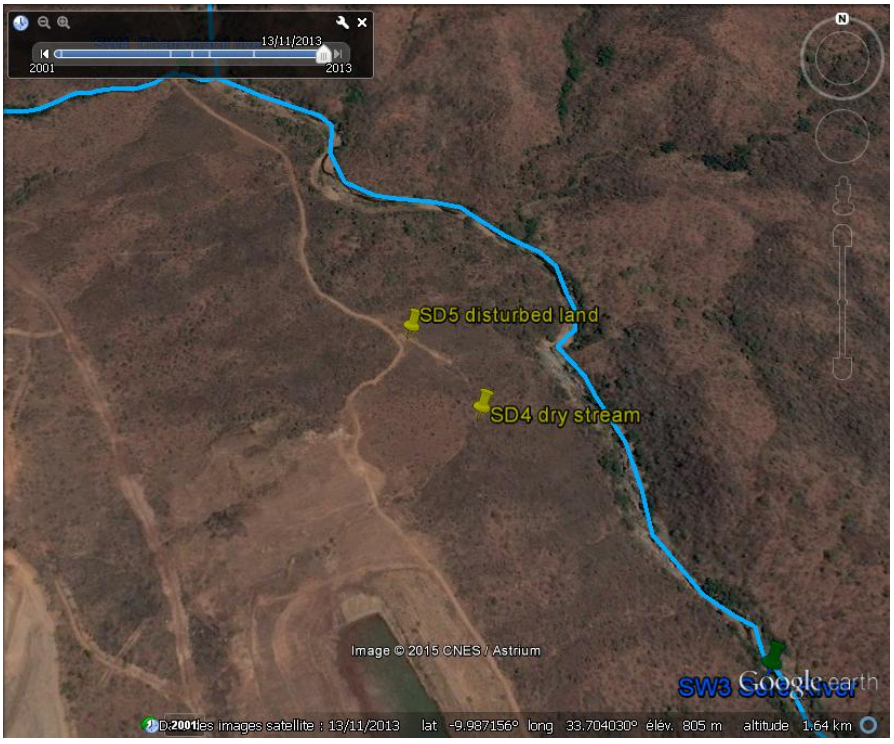


Fig. 54

Sample SD5 (disturbed land) collected on the eastern slope of the uranium mine (November 2013 satellite image) / soil perturbation is seen on the picture, water is seen in the reservoir

Source: GoogleEarth-CRIIRAD

Fig. 55

View of the mine, raw water dams and TSF (November 2013 satellite image)

Source: GoogleEarth-CRIIRAD

5.6 River sediments collected underwater

Four samples of river sediments have been collected by CRIIRAD and CFJ in May 2012, at the same locations of surface water samples. All samples were under water. Therefore the flux of gamma radiation was monitored on the bank of the river 1 to 2 meters from the place where the sediments were collected.

The locations for sampling of sediments were selected taking into consideration the structure of the sediments (as fine grained as possible) and the gamma radiation rates on the banks of the rivers.

- SD1: fine sand of the Sere River collected upstream of the confluence of the Chapwasha river. This sample is therefore a reference being out of the influence of the coal mine and uranium mine (gamma flux of 150 c/s at the surface).
- SD2: fine sand of the Chapwasha River collected about 150 m from the confluence with the Sere river (gamma flux of 110 c/s at the surface). Unfortunately the sample has been lost during the mission and could not be analysed.
- SD3: fine grained sediments of the Sere River collected about 1.6 km downstream of the Champhanji stream. This location is downstream of the raw water dams but upstream of the tailings storage facility TSFA (gamma flux of 120 c/s at the surface); see **Fig. 29**.
- SD8: fine sediments of the North-Rukuru river collected after the confluence of the Sere river, about 12 km downstream of the mine (gamma flux of 150 c/s at the surface); see **Figs. 13-14**.

Sampling locations of sediments SD3 and SD8 are plotted in **Fig. 56** below.

Fig. 56

Location of sediment samples SD3 and SD8 (November 2013 satellite image) / lake Malawi appears on the right corner.

Source: GoogleEarth CRIIRAD

In all three sediments, the activities of uranium 238 and its decay products are typical of a “natural” situation (28 to 62 Bq/kg dry) with no disequilibrium between uranium 238 and radium 226 (taking into consideration the uncertainties of the measurements). The activity of uranium 238 and its daughter products is twice as high in sample SD3 (downstream the uranium mine) compared to sample SD1 (upstream), but differences in the granulometry of the samples would have to be monitored in order to conclude.

No anomaly is detected regarding thorium 232 (34 to 69 Bq/kg dry) nor potassium 40 (660 to 840 Bq/kg dry).

The results of the radiological analysis are given in **table 5**.

Table 5 Analysis of sediment samples collected in May 2012 in the Sere and North-Rukuru rivers (gamma spectrometry at CRIIRAD laboratory)

Source: CRIIRAD

Code	Location	Description of sample	Uranium 238 (Thorium 234) (Bq/kg dry)*	Thorium 230 (Bq/kg dry)*	Radium 226 (Bq/kg dry)	Lead 210 (Bq/kg dry)*	U 235 (Bq/kg dry)	Thorium 232 decay chain : actinium 228 (Bq/kg dry)	K40 (Bq/kg dry)	Caesium 137 (Bq/kg dry)
SD 1	**Sere river** upstream path leading to Nkhachira (upstream confluence with Chapwasha river)	Fine sand under water (right bank)	31 ± 26	<80	30 ± 7	28 ± 18	<11	52 ± 13	660 ± 110	< 0.8
SD 3	**Sere river** downstream Champhanji river and open pit	Fine grained sediment (1 cm) under water (right bank)	62 ± 24	<80	64 ± 10	57 ± 18	<9	34 ± 9	710 ± 100	< 0.5
SD 8	**North Rukuru river** (old bridge) / downstream Sere river	Fine sediments (under water)	50 ± 30	<90	36 ± 8	44 ± 21	<11	69 ± 16	840 ± 130	< 0.8

* Due to the low energy of the gamma line used the activity may be underestimated (selfabsorption)

6 Results of independent monitoring of radon in the air

6.1 Introduction / methodology

Radon 222 is a radioactive gas created by the disintegration of radioactive radium 226 contained in the uranium 238 decay chain. General information about radon can be found in EJOLT report N°15, page 33-34[11].

It is extremely important to monitor radon activity in the open air in the surroundings of a uranium mine, taking into consideration the source terms (open pit, uranium ore piles, waste rock dumps, tailings dumps, etc..).

On a methodological point of view, it was not possible to monitor radon properly in the open air in the course of the short mission performed by CRIIRAD and CFJ in May 2012 (only 4 days on site).

Indeed, the activity of radon in the air varies greatly over time (day-night variations and seasonal variations). In order to make environmental impact assessments, it is recommended to make long term measurements (monthly or quarterly).

In the open air, the typical radon 222 activity is usually about a few to a few tens of Bq/m3.

It may be much higher in places where the soil has a high uranium content. According to the 1990 EIA (2006 EIA, page 6-127), the average outdoor radon concentrations were 10-17 Bq/m3 in the Kayelekera valley, 26-42 Bq/m3 at the exploration camp, 8-26 Bq/m3 at Nkhachira and 12-13 Bq/m3 at Karonga. But much higher values were detected:

[11] Ejolt Report N°15, page 33-34: http://www.ejolt.org/wordpress/wp-content/uploads/2014/11/141115_U-mining.pdf

"The 1990 study also found considerably higher long term average values between 100 to 600 Bq/m³ occurring directly above the uranium ore body and above the Champhanji River. The higher concentrations in proximity to the Champhanji River were attributed to the fact that the stream runs in a natural amphitheatre at this point, where air movement is more restricted than on the proposed mining site. Also, the Champhanji River itself is a source of radon, as it is fed at least in part by a radioactive spring. Measured daily average concentration above the Champhanji River reaches over 3 000 Bq/m³ and above the River strong diurnal trends in radon and radon daughter concentrations were observed. Similar trends were observed at Kayelekera Village. In both cases, highest concentrations occur at late evening and early morning during still air conditions. Lowest air concentrations occur at mid-afternoon when atmospheric stability is most disturbed by convective air currents. At the Champhanji River, daily average equilibrium factors in the range of 0,04 to 0,08 occur, indicating close proximity to the immediate source of radon. At other locations, e.g. Kayelekera Village, daily average equilibrium factors in the range 0,4 to 0,5 were found. This was stated as representative of a true equilibrium for the region, somewhat lower than the "typical" value of 0,8".

As it was difficult to install and leave radon monitors in the outside air, CRIIRAD decided instead to monitor radon inside some buildings.

Inside buildings, the radon permanently produced by the soil and building materials may accumulate to much higher values than the ones monitored outdoor.

The CRIIRAD technician installed six radon passive monitors (Kodalpha, provided by DOSIRAD laboratory) inside some dwellings or buildings in Kayelekera.

The locations have been selected after discussions with the community: three private houses, the community hall of Kayelekera, and the office of the directors inside the primary and secondary school.

The detectors have been installed on May 20th to 22nd 2012 and were collected by M. William Nyirenda, a CFJ member, on February 5Th 2013 and sent by Mail to CRIIRAD.

Only 4 detectors were still in place during the collection.

6.2 Results

The results of indoor radon monitoring are given in table 6 below along with the results of gamma radiation monitoring inside the buildings (results in counts per second with a DG5 scintillometer) and a description of the locations.

Table 6 Results of radon monitoring inside dwellings in Kayelekera

Source: CRIIRAD and CFJ

Village or city	Nkhachira	Kayelekera	Kayelekera	Kayelekera	Kayelekera	Kayelekera
Building and name of inhabitant	**Private house / Kayelekera village chief**	**Community hall**	**Primary school /office of headmaster M. Simbeye**	**Private traditional house / M Charles Sibale**	**Private traditional house / M Steve Kapira**	**Secondary school / office of director M Arnold Kapinga**
Radon 222 activity (Bq/m3)	**72 ± 14 Bq/m3**	**123 ± 22 Bq/m3**	**114 ± 21 Bq/m3**	Lost	Lost	**77 ± 14 Bq/m3**
Location code	R1	R2	R3	R4	R5	R6
Detector N°	394350	394351	394352	394353	394354	394355
Beginning (day, hour)	20/05/2012 12H	22/05/2012 12H15	22/05/2012 13H20	22/05/2012 14H	22/05/2012 14H50	22/05/2012 15H20
Name of operator	CCO-BC-WN	CCO-BC-WN	CCO-BC-WN	CCO-BC-WN	CCO-BC-WN	CCO-BC-WN
End (day, hour)	5/2/2013 16H26	5/2/2013 9H31	5/2/2013 9H	Lost	Lost	5/2/2013 9H15
Name of operator	WN	WN	WN			WN
GPS	S9 59.455 E33 40.433	S9 58.028 E33 40.967	S9 57.989 E33 40.963	S9 58.046 E33 40.969	S9 58.061 E33 41.125	S9 58.213 E33 41.340
Type of house	Bricks	Bricks	Bricks	Mud and wood	Mud and wood	Bricks
Type of room	Sitting room	Hall	Office	Sitting room	bedroom	office
Height of detector (m)	2 to 2.2	2 to 2.2	2 to 2.2	2 to 2.2	2 to 2.2	2 to 2.2
Type of Soil	Concrete slab	Concrete slab	Concrete slab	black paper covering brikcs and mud	bare soil	Concrete slab
Gamma radiation on soil (c/s DG5)	190	120	170	150	170	180
Gamma radiation 1 m above soil (c/s)	170	110	140	130	150	160
Type of walls	Bricks and cement	Bricks and cement	Bricks and cement	mud and wood	mud and wood	Bricks and cement
Gamma radiation on walls (1 m above soil), c/s	180	140	160	150	160	200
Windows	one	none	two (constantly open)	none	none	one (constantly open)
Door	one open	one closed	one closed	one open	one closed	one
Picture	yes	yes	yes	yes	yes	yes
Other comments	high air exchange with exterior	high air exchange with exterior	moderate air exchange with exterior	high air exchange with exterior	moderate air exchange with exterior (roof)	high air exchange with exterior

The recommendations of the World Health Organization are summarised below :

“A national Reference Level does not specify a rigid boundary between safety and danger, but defines a level of risk from indoor radon that a country considers to be too high if it continues unchecked into the future. However, protective measures may also be appropriate below this level to ensure radon concentrations in homes are well below that level. In view of the latest scientific data, WHO proposes a Reference Level of 100 Bq/m3 to minimize health hazards due to indoor radon

exposure. However, if this level cannot be reached under the prevailing country-specific conditions, the chosen Reference Level should not exceed 300 Bq/m3 which represents approximately 10 mSv per year according to recent calculations by the International Commission on Radiation Protection."

The mean radon 222 activities in the buildings tested by CRIIRAD and CFJ in Kayelekera are comprised between 72 Bq/m3 (private house in Nkhachira) and 123 Bq/m3 (community hall in Kayelekera). These results show that radon inhalation is a non-negligible contributor to the dose received by the population.

According to Paladin, the average radon concentrations monitored indoor during the 1990 EIA (page 6-128) were : 20-40 Bq/m3 in Kayelekera Valley, 80-90 Bq/m3 at the exploration camp and 20 to 40 Bq/m3 at Nkhachira.

Additional studies would be necessary to evaluate the amount of radon which is of natural origin and the proportion that may be due to the dispersion of radon into the atmosphere since the commissioning of the mine.

CRIIRAD recommends that PAL provides to the community the results of outdoor and indoor radon monitoring in the open air in the environment of the mine.

According to Paladin environmental monitoring technicians met in Kayelekera in May 2012, there are 10 air monitoring posts inside the mine perimeter and immediate environment.

7 Conclusions and recommendations

CRIIRAD could find no results of Paladin Africa Limited Environmental monitoring program performed after the commissioning of the uranium mine.

The recommendations below are based on 3 different sources of data :

- the results of the in situ monitoring campaign performed by CRIIRAD and CFJ in Kayelekera in May 2012,
- the analysis of the public documentation provided by PAL (mainly the 2006 EIA).
- CRIIRAD experience about the impact of uranium mining activities based on previous studies in Europe, Africa or Brazil.

7.1 Serious lack of transparency of the Paladin company

CRIIRAD could find no results of PAL (Paladin Africa Limited) Environmental monitoring program performed after the commissioning of the uranium mine.

M. Reinford Mwangonde (CFJ) confirmed in December 2014 that the organisations of the Civil Society still have no access to this information. Paladin asks people to get the information from the government of Malawi which in turns answers that the reports belong to the company.

This situation is not acceptable and in contradiction with Paladin official policy.

Indeed, Paladin 2013 Sustainability report states that :

Page 14 : “Paladin’s environmental approach is managed through the Company’s Environmental Policy11, which focuses on: …/… reporting openly and transparently on the Company’s environmental performance.”

Page 33 : “Paladin established a Community Relations Policy with the aim of achieving a balance between economic, environmental and social needs. The Policy outlines Paladin’s commitment to .. /..being open and transparent in all communications..”.

Page 26 : “The methodology aims to ensure that employees are involved through effective communication and information sharing.”

Paladin 2012 and 2013 Sustainability reports which are available on Paladin website give no information about the results of the radiological environmental monitoring performed in Kayelekera. The sections “Health and Safety” of these reports deal with injuries, AIDS, vaccination or malaria but no information is given about radiation doses received by the workers or local population.

During the visit of the Parliamentary Committee for Natural Resources and Climate Change in October 2014, some information was given by PAL about the type of environmental controls but again no results were provided. According to the website “Miningmalawi.com”[12], Bruce Ryan (Safety, Health, Environment & Radiation) made a presentation. Some elements are reproduced below including **Fig. 57**:

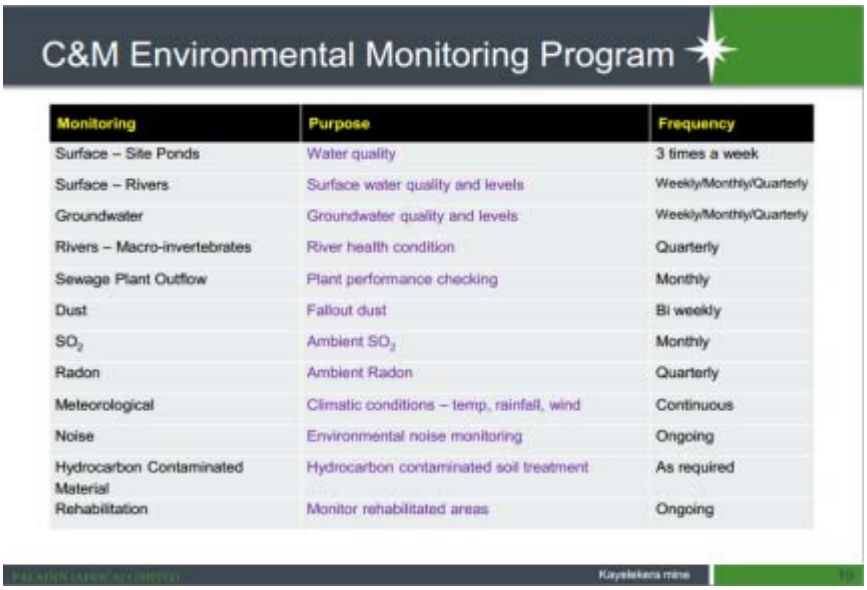
“Four rivers (Chapwasha, Sere, Muswanga and North Rukuru) and two streams (Champhanje and Kantchindu) as well as occupational and physical radiation are regularly monitored. This includes continuous gamma exposure monitoring per worker, random gamma surveys around the site and monthly surveying of radiation surface contamination (such as of offices, tea rooms, vehicles and equipment). Monitoring is also conducted outside the mine site.

Quarterly reports are submitted to the Environmental Affairs Department and independent analyses are sent directly to the Department.”

Fig. 57

Care and Maintenance Environmental Monitoring Program

Source: Paladin Africa presentation at Extraordinary DEC Meeting, Karonga, 28 October 2014



The table above gives some general information about Paladin environmental monitoring program, but again no detailed results of environmental monitoring were given by PAL during this presentation. Without detailed data, it is impossible to assess the effectiveness or shortcomings of the environmental monitoring plan.

[12] http://mininginmalawi.com/2014/11/23/inside-malawis-largest-mine-parliamentary-visit-to-paladin-africas-kayelekera-uranium-mine/

Results that relate to the radiological monitoring of the environment are kept secret. Paladin Africa Limited should publish on its web site all environmental reports. No property right can be invoked to prevent public access to Paladin environmental reports (especially as Malawi State holds 15 % of the shares of the uranium mine)

Results that relate to the radiological monitoring of the environment are kept secret. The company should publish on its web site all environmental reports. No property right can be invoked to prevent public access to Paladin environmental reports (especially as Malawi State holds 15 % of the shares of the uranium mine).

7.2 Exposure of the workers to radiation

During CRIIRAD May 2012 mission to Kayelekera, workers of the uranium mine complained that the results of the individual dosimetry tests were not given to them. This situation must be corrected. In coherence with Paladin official policy (see above) and in application of international labour laws, each worker must be given the detailed results of radiation monitoring (external irradiation, internal contamination, etc..).

During the visit of the Parliamentary Committee for Natural Resources and Climate Change in October 2014 some information was given by PAL about the "mean" doses received by the workers. According to the website "Miningmalawi.com"[13], Bruce Ryan (Safety, Health, Environment & Radiation) made a presentation. Some elements are reproduced below:

"According to Ryan, radiation exists slightly above background levels. The limit is 20 milliSieverts, which is the average accumulated background radiation dose to an individual for 1 year, exclusive of radon. The highest level at the mine is 3 mSv".

This statement, if properly quoted, is misleading. The limit of 20 milliSievert is not background radiation, it is the maximum annual limit of radiation received by a worker of the nuclear industry above background radiation and it does include radon in the case of uranium mining workers. The table showed during the presentation (see **Fig. 58**) shows mean doses but it does not give maximal doses received by individual workers.

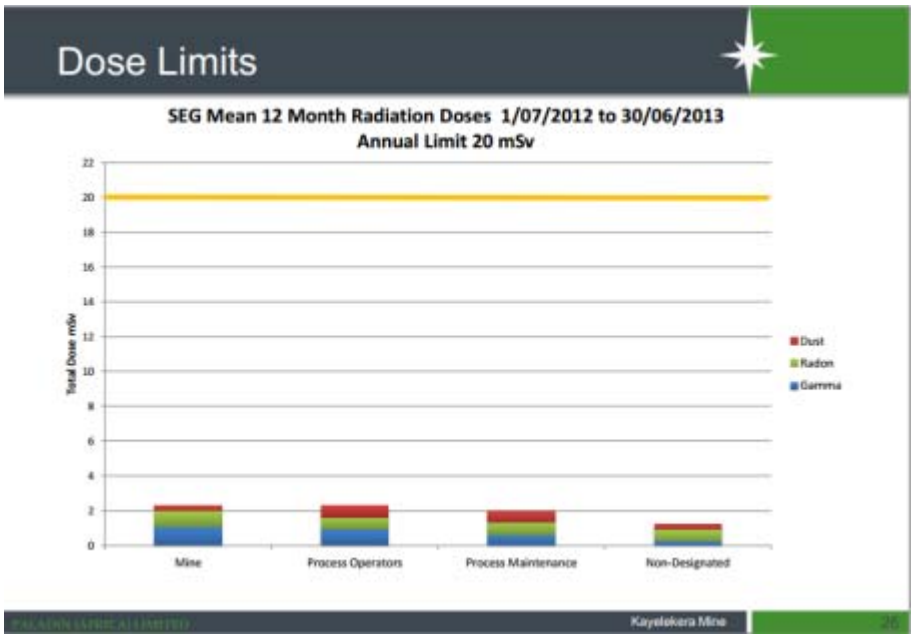
It is important to note that the effective dose limit of 20 mSv per year for workers corresponds to a high level of risk.

[13] http://mininginmalawi.com/2014/11/23/inside-malawis-largest-mine-parliamentary-visit-to-paladin-africas-kayelekera-uranium-mine/

Fig. 58

Radiation Dose Limit and Monitoring

Source: PaladinAfrica presentation at Extraordinary DEC Meeting, Karonga, 28 Octob er 2014



For the probability of cancer (fatal and non-fatal) among workers, the International Commission on Radiological Protection (ICRP)[14] acknowledges a risk estimate of 11.67.10-2.Sv-1. This means that, if 10 000 workers are exposed to a dose of 20 mSv, it is estimated that 23 of them will develop a cancer caused by their exposure to radiation.

The effective dose limit of 20 mSv per year for workers corresponds to a high level of risk

In addition, various epidemiological studies, reinforced by biological and theoretical studies, indicate that it is no more appropriate to apply the Dose and Dose Rate Effectiveness Factor (DREFF) of 0.5 used by the ICRP. Therefore, the actual risk would be 2 times higher: 46 cases of cancer per 10 000 workers exposed to 20 mSv. This assessment does not take into account the radiation-induced hereditary disorders (genetic damage transmitted to offspring), nor the non-cancerous pathologies demonstrated in several cohorts of populations or workers exposed to radiation (Chernobyl liquidators, inhabitants of contaminated territories, etc.).

For the probability of fatal cancer, the ICRP acknowledges a risk of 3.15 10-2.Sv-1. i.e. 6.3 10-2.Sv-1 without application of the DREFF. So, if 10 000 workers are exposed to a dose of 20 mSv, we can estimate that 13 of them will die of cancer caused by their exposure to radiation. It is not certain that the non-fatal cancer rate used by ICRP applies to countries like Malawi, as it will depend on the treatments available. So, probably, the real number of fatalities will be higher.

In its recommendations of 1977, the ICPR stated that, to assess the acceptability of risk for workers exposed to radiation, it was useful to compare the radiation-induced mortality with the mortality of the workers employed in the safest industries. At that time, ICRP considered that a risk of 10-4 (1 death per 10 000

[14] The 2007 recommendations of the ICRP, ICRP Publication 103, 2007.

The mean dose of about 2 mSv mentioned by Paladin is not a satisfactory achievement but rather a maximum tolerable level of risk.

workers) was representative of the safest industries. The effective dose limit recommended in 1977 by ICRP was 50 mSv / year. This value corresponded to a risk six times higher than the reference of 10-4. As a result, the ICRP asked competent authorities to ensure that only a small number of workers would be exposed to doses close to the limit. When considering all the workers, the effective dose limit had to be 10 times lower, i.e. 5 mSv / year.

Based on the risks factors of ICRP 103 (2007) and a probability of fatal cancer of 6.3 10-2, in order to ensure compliance with a level of fatal cancer of 10-4, the effective dose limit should not exceed 1.2 mSv/year (2.4 mSv/y if DREFF is still applied). Moreover, since 1977, significant progress has been made in terms of safety and it is likely that the mortality risk coefficient in the safest industries is well below 10-4. Therefore, the mean dose of about 2 mSv mentioned by Paladin is not a satisfactory achievement but rather a maximum tolerable level of risk.

In addition, there is no evidence that the Paladin dose assessments are reliable. Paladin should provide detailed information about the equipment and methodologies used to monitor the external and internal exposure of workers to radiation (including urine tests) and provide detailed maps of outdoor and indoor radon activity on the site, gamma radiation, radioactivity of dust, etc...

It is important to check also if the monitoring takes into consideration the doses received by the workers living on the mine after their working hours as they may be submitted to non-negligible additional doses. According to Paladin 2006 EIA (page 2-29) “on-site accommodation will be provided for expatriate staff” including “family units “. Indeed, Paladin decided to build the residential area on the site of the mine instead of installing it in less radioactive places. Paladin also used potentially radioactive waste rocks for Construction of road surfaces, engineered terraces, etc.. The workers may also be exposed to high outdoor and indoor radon as the camp is not far away from the TSF and open pit.

Paladin should also take into consideration the doses received by the workers when ingesting water abstracted from the Sere river and “additional amounts potentially sourced from dewatering boreholes situated on the western perimeter of the open pit” (EIA 2006, page 2-26). As explained above, the radiological characteristics of the water may exceed WHO standards. Indeed, CRIIRAD monitored in May 2012, a uranium concentration of 42.8 µg/l in the Sere River, about 1.6 km downstream the confluence with the Champhanji river. This value is exceeding WHO guideline of 30 µg/l.

Paladin should also explain:

- how the health status of the workers will be monitored on the long term taking into consideration the fact that radiation induced pathologies sometimes appear decades after exposure, and
- what financial resources will be allocated in order to cure and compensate workers that will become sick in the long term.

Additional information about health risks connected to exposure to uranium and its daughter products are given in EJOLT report N°15[15].

7.3 Evaluation of people exposure to radiation in the village of Kayelekera

During a short (4 days) mission to Kayelekera (May 2012), CRIIRAD and CFJ performed limited radiation monitoring checks in the village. The main results were presented in sections 3 to 6 of the present report and are summarised below.

Gamma radiation

During the mission, CRIIRAD team used a scintillometer (DG5) to check gamma radiation rates inside the vehicle on the road from Karonga to Kayelekera, from Kayelekera to the gate of PAL uranium mine and from Kayelekera to Nkhachira and to the coal mine. No evidence of readings higher than typical background were found, except abnormal values detected on the road leading to Nkhachira (see below).

These measurements revealed no reuse of radioactive waste rocks in the village of Kayelekera or the road from Kayelekera to the uranium mine entrance, but according to Paladin EIA report waste rocks have been re-used for construction inside the mine perimeter.

Measurements where performed also while walking in Kayelekera village, inside a selection of private houses and public buildings (schools and community hall). Typical values ranged from 110 to 190 c/s on the surface of the ground and the walls of the dwellings. Such values are due to the amount of natural radionuclides in the soil (uranium 238, thorium 232, potassium 40). Identical values have been monitored by CRIIRAD in France, in natural areas where the soil is of granitic type, while much lower values (50-100 c/s) are monitored on limestone.

Higher levels of radiation (840 c/s) were discovered in the area of Nkhachira on sand accumulated by drainage of sandstone on a path leading to the village. The higher radiation values are due to elevated concentrations of uranium 238 (600 Bq/kg) and thorium 232 (2 160 Bq/kg). CRIIRAD advised the chief to recommend to the community not to use this sand for building purposes taking into consideration the risk of exposure to gamma radiation and the risk of enhanced concentration of radioactive radon isotopes. Villagers confirmed that they get the sand from the Sere river. The radioactivity of the sand and sediments analysed by CRIIRAD in the Sere river upstream of the uranium mine is normal (uranium 238 and thorium 232 activities close to or below 50 Bq/kg).

Radiation checks performed at 4 different houses where “black paper” coming from the uranium mine was re-used for covering the roof did not show abnormal radiation rates. But there is a risk of re-use of contaminated scrap or recycled

[15] Ejolt Report N°15, page 74-82: http://www.ejolt.org/wordpress/wp-content/uploads/2014/11/141115_U-mining.pdf

material from the mine. Indeed thieves are confirmed by the mine Safety manager that showed us a hole in the fence of the mine. He said that people were illegally entering the mine for getting tyres, batteries or other equipment. Paladin should improve the quality of the fence. Regarding Paladin methodology for testing scrap before clearance, the 2006 EIA (page ES-67) mentions surface contamination tests with a limit of 0.4 Bq/cm2 for alpha emiters. The testing methodology should be made public. CRIIRAD advised the community to make independent monitoring on all the material coming from the mine. A portable radiation monitor has been given by CRIIRAD to the community.

When the trucks carrying uranium concentrate ("yellow cake") pass on the main road in the middle of the village, people may be exposed to gamma radiation. In the case of AREVA's uranium mines in Niger, the data provided by the company shows that the dose rate on the drums varies from 5 to 12 µSv/h, which is about 25 to 60 times above the local natural background rate. At a distance of 1 meter from the drums, the dose rate is still 2 to 4 µSv/h, which is 10 to 20 times above natural background. On contact with the trucks loaded with the drums, the dose rate is 12 to 19 µSv/h, which is 60 to 95 times above natural background. At a distance of 2 metres from the trucks loaded with drums, the dose rate is 1.2 to 4.7 µSv/h. This is 6 to 24 times above natural background radiation.

Workers confirmed that about two trucks containing yellow cake are passing through Kayelekera every month. CRIIRAD could not monitor such trucks but advised the community not to stay close to such trucks and to check that the vehicles do not stop in the village.

Paladin reported that accidents occurred during the transportation of chemicals or radioactive products (two tonnes of MgO in January 2013, uranium concentrate in February 2014, etc..). Independent monitoring should be performed in order to check if all the spilt material and contaminated soil has been recovered.

Water used for human consumption

Three samples of underground water used by the community in Kayelekera were tested for chemicals and radionuclides. The radiological characteristics of the sample collected near the football ground on the right bank of the Sere river were below WHO standards. But the regular consumption of the water from the production borehole located near the primary school and of the artesian borehole will induce a dose to the consumer which is exceeding the guideline of 0.1 milliSievert per year taking into consideration the activity of radon 222.

This situation is probably of natural origin, as shown by the monitoring performed prior to the opening of the mine (2006 EIA report), but it is shocking to realise that the dose due to the activity of uranium 238 daughter products mentioned in an appendix to the 2006 EIA report was strongly underestimated (1.5 microSievert per year instead of 763 microSieverts per year as estimated by CRIIRAD for the artesian borehole).

It should be noted also that people in the area use water from other boreholes, and from the Sere river and other springs-streams for human consumption. Some

of these water resources will probably be impacted by the mining activities, either by fallout of radioactive dust and radon decay products on the soil, either by spillage, direct discharges and contamination of underground water resources.

Detailed monitoring of underground and surface water samples is necessary to assess the risks for the population. For this purpose, it is necessary to obtain copies of the monitoring campaigns performed by Paladin Africa and submitted to the competent authorities of the government of Malawi. If a comprehensive monitoring is not performed, the authorities should impose one to the mining company. It should include the monitoring of dissolved radon, gross alpha, and gross beta activity, the activity of uranium isotopes, radium 226, lead 210, polonium 210, etc.; the monitoring of main anions and cations, metals and organic pollutants.

Radon

Radon 222 activity was checked in 4 buildings and showed values between 72 Bq/m3 (private house in Nkhachira) and 123 Bq/m3 (community hall in Kayelekera). These results show that radon inhalation is a non negligible contributor to the dose received by the population.

Additional studies would be necessary to evaluate the amount of radon which is of natural origin and the proportion that may be due to the dispersion of radon into the atmosphere since the commissioning of the mine. CRIIRAD recommends that PAL provides to the community the results of outdoor and indoor radon monitoring in the environment of the uranium mine. According to Paladin Environmental monitoring program (see **table 53** above) ambient radon is monitored quarterly.

It would be useful to get a general mapping of radon activity including the mining site and its environment with a sufficient and representative number of control stations.

Dust

The analysis of samples of top soil collected in Kayelekera and Nkhachira did not reveal abnormal concentration of radioactive material (uranium 238 and thorium 232 activities close to or below 50 Bq/kg). But these limited tests are not sufficient to evaluate the impact of the mining activities in terms of radioactive dust in the air (especially during blasting activities), and radioactive dust deposition on the soil and crops.

In order to evaluate the impact, it would be necessary to get detailed results of the monitoring network operated by Paladin in order to check if the samplers are located at appropriate locations taking into consideration the source terms, typical wind directions and location of the villages. It is important to check also if the monitoring methodology enables to detect all the radionuclides associated with uranium and thorium. According to Paladin Environmental monitoring program (see Fig. 57), fallout dust is monitored bi-weekly, but the table does not say if PAL is monitoring the radiological characteristics of the dust or only the amount of dust.

It is shocking to discover that these radioactive and chemically polluting wastes are disposed of on a plateau with very negative geological and hydrogeological characteristics.

Food chain and bioindicators

Due to the limited amount of financial resources, CRIIRAD could not monitor the radioactivity of the food chain or bioindicators in Kayelekera. As the uranium mine may have an impact on the crops (deposition of radioactive dust and radon decay products) and fish (impact on the Sere river), independent monitoring should be performed.

According to Paladin Environmental monitoring program (see **Fig. 57** above), it seems to be that Paladin is not monitoring the food chain nor the sediments and aquatic flora in the rivers as only underground water and surface water quality is mentioned. Some monitoring is done of macro-invertebrates but it is not clear if the monitoring is about radiological or chemical contamination or only the inventory of the species. This situation should be clarified and the monitoring programs upgraded.

7.4 Detection of hot spots on the eastern slope of the uranium mine

The measurements of gamma radiation performed in May 2012 by CRIIRAD and CFJ while walking on the eastern toe of the Kayelekera uranium mine revealed hot spots.

The highest readings were obtained on a black rock laying besides the path (2600 c/s which is more than 13 times above local background) and on the soil of a disturbed place located about 330 from the bottom of Runoff water pond N°1 (1 600 c/s). In this second case, the elevated radiation is clearly due to industrial activities (see discussion page 35-38). The local population may have access to the area and be exposed to the radioactive material.

PAL should provide comments about the origin of these hot spots and rehabilitate the area.

CRIIRAD recommends also that a gamma radiation survey of the surroundings of the uranium mine be performed by Paladin and the results made public.

7.5 Management of the radioactive wastes

Uranium mining in Kayelekera will produce huge amounts of radioactive wastes including, as indicated in Paladadin EIA : 13 million tonnes of tailings and 9.1 million m3 of waste rocks.

Taking into consideration the half-life of uranium 238 (4.5 billion years) and thorium 230 (75 000 years) these wastes will be radioactive for extremely long durations. They also pose problems due to their chemical characteristics :

According to Paladin 2006 EIA (page 2-56 and 2-57): “It can be concluded that the tailings might be potentially acid generating, with slightly acidic leachate and this may result in the contaminating the groundwater”. The sulphate concentrations of

the tailings leachate may be high, greater than 2 000 mg/ℓ. The manganese concentration in water emanating from the tailings material will also be high".

It is shocking to discover that these radioactive and chemically polluting wastes are disposed of on a plateau with very negative geological and hydrogeological characteristics:

- The plateau is surrounded by rivers on all sides including the Sere river which flows into the North Rukuru river and lake Malawi.
- The area has a non negligible seismicity. According to 2006 EIA (page 6-22) : "The Kayelekera Uranium Project is located within an area containing Cenozoic Rift faults and reactivated Pre-Cenozoic faults and lies close to an area of high seismic activity in Malawi". "Earthquakes in the vicinity of Kayelekera generally range between magnitudes of 3,0 to 4,9 on the Richter Scale, however, it is expected that earthquakes up to magnitude 6,5 are possible."
- There are "fault lines" within the project area and under the tailings storage facilities.
- There are high rainfall events and a strong erosion. According to Paladin 2006 EIA (page 6-35) : "During the peak of the rainy season, these rains can be very intense, causing significant erosion of the landscape".
- In addition, the radioactive wastes are not properly confined and they put at high long term risk the whole area. This situation is not acceptable.
- We suggest that the citizens of Malawi ask Paladin to answer the following questions:
- What are the radiological and chemical characteristics of the tailings? According to CRIIRAD calculation, taking into consideration the activity of the ore, the total activity of the tailings is probably about 100 000 Bq/kg. The 2006 EIA does not give detailed radiological characteristics of the tailings as the dedicated section (2-60), gives only the gross alpha and gross beta activities of the tailings supernatant (8.28 and 4.5 Bq/l) and tailings slurry (112.6 and 27.3 Bq/l).
- How is monitored the impact of airborne transfer of contaminants from the surface of TSFA (radioactive dust and radon gas) ?
- What is the annual amount of water seeping from the base of the dam of TSFA and collected in the seepage detection dam ? What are the radiological and chemical characteristics of these waters ?
- How many boreholes are used to monitor the quality of the underground water in the surroundings of TSFA, at what depth and location ? What are the results of the monitoring ?
- According to Paladin 2006 EIA (ES-14): "Each facility will be designed to withstand the 1:475 year return period seismic event and the 1:100 year return period 24-hour storm event". What will happen in case of earthquakes or

Impact is detected in the Sere river, 1.6 km downstream, where the uranium concentration monitored in May 2012 was 42.8 µg/l which is 194 times higher than the level monitored upstream of the mine (0.22 µg/l).

storms exceeding these ones? Could Paladin produce a copy of the emergency response plan in case of dam failure ? What studies have been done to evaluate the long term stability of the dam of TSFA ? In case of a breaking of the dam (violent storms with heavy rain, earthquakes), the situation will be catastrophic.

- • According to Paladin 2006 EIA (page ES-73): “The closure plan must include the requirements for institutional control of areas that could still potentially pose a radiation risk after closure (i.e. TSFs”. How will PAL and the government of Malawi guarantee the long term monitoring of the stability of the TSF? Who will pay for this ?
- • How long is Paladin intending to maintain the pumping equipment designed to pump back the contaminated seepage water that is leaking through the TSFA basin lining and grout curtain ?

7.6 Uncontrolled discharge of liquid effluents

CRIIRAD and CFJ made an independent monitoring of the Champhanji stream (located below the open pit and flowing into the Sere river). The results shows that a contamination is taking place especially with uranium and sulfates whose concentrations are much higher than before the commissioning of the uranium mine.

In May 2012, the uranium concentration in the Champhanji stream was 5 230 µg/l or 65 Bq/l while according to the 1990 EIA, it was only between 0.05-0.24 Bq/l (wet season) and 1.4 Bq/l (dry season) before the commissioning of the mine.

This impact is detected in the Sere river, 1.6 km downstream, where the uranium concentration monitored in May 2012 was 42.8 µg/l which is 194 times higher than the level monitored upstream of the mine (0.22 µg/l), (see page 23-26).

In addition, Paladin acknowledges various spills, for example in March 2013 and January 2015, but the company does not publish the detailed results of the environmental monitoring.

A detailed monitoring of surface water samples (and other environmental samples including sediments, fauna and flora) is necessary to check the impact of leakages and spills from the uranium mine (open pit, waste rock dumps and TSFA) on the Sere river and North Rukuru river downstream the mine. It is extremely important to get samples immediately downstream the TSFA.

It is necessary to obtain copies of the monitoring campaigns of surface water, sediments and biota performed by Paladin Africa. Unfortunately, Paladin 2012 and 2013 Sustainability reports which are available on Paladin website give no information about the results of the environmental monitoring performed in Kayelekera. More detailed reports including these results are probably prepared and submitted to the competent authorities of the government of Malawi, but, if it is the case, the results are kept secret.

7.7 Controlled discharge of liquid effluents

In contradiction with the statements of the 2006 EIA report, Paladin is planning to discharge up to 450,000 cubic metres of effluents per year in the Sere river. Paladin confirmed on November 20th 2014 that it "plans to begin the controlled release of surplus water into the local river system in early 2015, but only after treatment". Paladin. Taking into consideration the information given by Paladin about this project (see **Appendix 4**), CRIIRAD wishes to make the following comments:

1. PAL does not provide sufficient information about the radiological characteristics of the water to be treated and the residual contamination of the water to be discharged in the Sere River. PAL indicates that it will monitor uranium and radium 226 but other radioactive elements are included in the run-off water like thorium 230, radon 222, lead 210 and polonium 210. Lead 210 and polonium 210 are among the most radiotoxic elements when ingested. Therefore PAL should provide detailed information about the amount of these radioactive elements in the untreated and treated water and clarify the discharge limits to be applied.

2. PAL does not provide sufficient information about the chemical characteristics of the water to be treated and the residual contamination of the water to be discharged in the Sere River. PAL indicates that it will monitor sulfates and calcium but, as shown by the independent monitoring of surface water collected by CRIIRAD in the Champhanji stream in May 2012 downstream to the open pit, other chemicals are included in the run-off water like arsenic, boron, barium, cadmium, lithium, manganese, molybdenum, selenium, strontium (see page 25). Other chemicals used in the uranium extraction process may also be present in the run-off water. Therefore PAL should provide detailed information about the amount of chemicals (heavy metals, other anions and cations, organic chemicals) in the untreated and treated water and clarify the discharge limits to be applied.

3. PAL does not give details about the water treatment methodology. With some treatment technologies, chemicals are used to facilitate the treatment and may themselves be found in the treated water and induce an environmental impact.

4. Regarding discharge limits for sulfates, PAL indicates a value of 800 mg/l. This value is quite high taking into consideration the environmental impact of sulfates in the aquatic environment. In some countries[16], the discharge limit for sulfates in surface water is set to much lower values, for example in Canada, guidelines for maximum sulfate concentration in surface waters for aquatic life protection is 100 mg/l (not to be exceeded) and 50 mg/l (alert level for aquatic mosses).

5. Regarding discharge limits for uranium, PAL indicates a value of 30 µg/l (microgram per liter). This value is quite high taking into consideration the environmental impact of uranium in the aquatic environment. Since decades, several studies have demonstrated adverse effects of uranium on the aquatic

[16] http://www.epa.ie/licences/lic_eDMS/090151b28005fa61.pdf

organisms at much lower levels. Recently, the French Radiation Protection and Nuclear Safety Institute (IRSN), in a report produced in 2014[17], evaluates a typical Predicted No Effect Concentration of 0.3 µg/l above natural background. The limit should be set for each situation depending on the other chemical characteristics of the water that will influence the speciation of uranium in the environment.

6. The contamination of run-off waters is a serious problem for the long term. At present PAL is still in a position to find financial resources in order to collect and treat the contaminated waters, but the question should be raised of the evolution of the situation after the closure of the mine in a few years. Who will take care of the facilities designed to collect and treat the contaminated waters? Studies performed by the CRIIRAD laboratory in France show that the rain water circulating on waste rock dumps carries radioactive elements even decades after the closure of the mine.

7. Paladin should not be allowed to discharge radioactive and chemical pollutants in the Sere river as long as it does not publish the full EIA and the results of its environmental monitoring.

[17] IRSN report PRP-ENV / SERIS / 2014-0028 “Proposition de valeurs de PNEC eau de l’uranium conditionnelles à des domaines physico-chimiques représentatifs des eaux douces françaises».

Acknowledgments

This work has been made possible thanks to the dynamics and resources of the EJOLT Project, which facilitated independent on-site radiological surveys near Kayelekera uranium mine. The EJOLT project also enabled training activities with affected communities.

Special thanks to Marta Conde for making initial contact with CRIIRAD in 2010, the initiative of involving CRIIRAD into EJOLT work and the continuous support to all the aspects of the project. Thanks also to UAB, especially Joan Martinez Alier and Beatriz Rodríguez-Labajos for supporting this initiative.

Thanks to Reinford Mwangonde, William Nyirenda and Chikondi Njawala (CFJ, Malawi) for organizing the May 2012 mission to Kayelekera and supporting all the activities performed there with the communities.

Thanks to the people of Kayelekera, the teachers of the village and the Chief of Kayelekera for their warm welcome and cooperation during the 4 days mission.

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ANNEX 1

Analysis of water samples collected by CRIIRAD in the course of the May 2012 mission to Kayelekera uranium mine

Note : the legend is reported at the bottom of table C1.

A1 Description of the samples and results of monitoring of radioactive substances

Sample Code (on site)	UW1	UW2	UW3	SW1	SW2	SW4	SW3	SW5
CRIIRAD Lab Code	280512A6	280512A7	280512A8	280512A1	280512A2	280512A4	280512A3	280512A5
Location	Drinkable water from a borehole at Kayelekera	Drinkable water from a borehole at Kayelekera	Drinkable water from a borehole at Kayelekera	Sere river upstream path leading to Nkhachira (upstream confluence with Chapwasha river)	Chapwasha river about 150 m from junction with Sere river	"Champhanji" river downstream open pit	Sere river downstream Champhanji river and open pit	North Rukuru river (old bridge) / downstream Sere river
Description	Hand pump close to Primary school	Hand pump close to football ground	Artesian borehole close to secondary school	Surface water (right bank)	Surface water (left bank)	Surface water of a stream	Surface water (right bank)	Surface water
GPS coordinates	S9 57.973	S9 58.211	S9 58.196	S9 58.052	S9 58.255	S9 58.942	S9 59.421	S9 56.620
GPS coordinates	E33 40.939	E33 40.650	E33 41.311	E33 40.866	E33 41.001	E33 42.014	E33 42.422	E33 46.503
Sampling time (local)	22/5/12 13:30	22/5/12 14:15	22/5/12 15:45	20/5/12 14:00	20/5/12 14:40	21/5/12 15:00	21/5/12 12:40	22/5/12 17:20

Anions and cations (semi-quantitative screening by ion chromatography) (a)									WHO guideline for drinking water
Ammonium mg/l	0	0	0	0	0	0	0	0	
Bromates mg/l	0	0	0	0	0	0	0	0	25 µg/l
Bromides mg/l	0	0	0	0	0	0	0	0	
Calcium mg/l	37	63	25	15	14	49	17	7,6	
Chlorate mg/l	0	0	0	0	0	0	0	0	
Chlorite mg/l	0	0	0	0	0	0	0	0	200 µg/l
Chloride (chlorures) mg/l	1,6	2,1	1,5	1,7	2,4	2	1,8	0	250 mg/l
Fluoride (fluorures) mg/l	0,051	0,11	0,03	0,1	0,12	0,14	0,13	0,054	1,5 mg/l
Magnesium mg/l	15	16	10	7,9	4,6	17	8,1	2,9	
Nitrates mg/l	0	0	0	0	0	0	0	0	50 mg/l
Nitrites mg/l	0	0	0	0	0,02	0	0	0	200 µg/l
Orthophosphates mg/l	0	0,04	0	0	0	0	0	0	
Potassium mg/l	2,3	1,2	2,2	2	2	1,8	2,1	1	
Sodium mg/l	127	45	132	10	11	40	12	4,8	200 mg/l
Sulfates mg/l	41	4,4	18	0	5,7	62	1,5	1,3	250 mg/l

B1 Results of the chemical analysis (anions and cations)

Note :water samples have been collected by CRIIRAD laboratory technicians in cooperation with CFJ members (1 liter plastic container with special cap)

Sample Code (on site)	UW1	UW2	UW3	SW1	SW2	SW4	SW3	SW5
CRIIRAD Lab Code	280512A6	280512A7	280512A8	280512A1	280512A2	280512A4	280512A3	280512A5
Location	Drinkable water from a borehole at Kayelekera	Drinkable water from a borehole at Kayelekera	Drinkable water from a borehole at Kayelekera	Sere river upstream path leading to Nkhachira (upstream confluence with Chapwasha river)	Chapwasha river about 150 m from junction with Sere river	"Champhanji" river downstream open pit	Sere river downstream Champhanji river and open pit	North Rukuru river (old bridge) / downstream Sere river
Description	Hand pump close to Primary school	Hand pump close to football ground	Artesian borehole close to secondary school	Surface water (right bank)	Surface water (left bank)	Surface water of a stream	Surface water (right bank)	Surface water
GPS coordinates	S9 57.973	S9 58.211	S9 58.196	S9 58.052	S9 58.255	S9 58.942	S9 59.421	S9 56.620
GPS coordinates	E33 40.939	E33 40.650	E33 41.311	E33 40.866	E33 41.001	E33 42.014	E33 42.422	E33 46.503
Sampling time (local)	22/5/12 13:30	22/5/12 14:15	22/5/12 15:45	20/5/12 14:00	20/5/12 14:40	21/5/12 15:00	21/5/12 12:40	22/5/12 17:20

pH and conductivity (on site monitoring by CRIIRAD with portable equipment)

pH	7.3	7.11	7.54	8.7	7.9	8.45	8.7	8.09
Water T°C when pH was measured	27.0	27.2	26.7	24.3	28.8	22.9	25.1	23.7
conductivity (µS/cm)	765	603	685	179	156	525	193	66

pH and conductivity (laboratory measurements) (a)

pH	7,75	7,60	8,00	8,35	7,65	8,15	8,15	7,50
Water T°C when pH was measured	22.6	22,7	22,7	22,8	22,8	22,9	22,8	22,9
Conductivity at 25 °C (µS/cm)	724	576	648	170	144	489	183	68
Conductivity at 20 °C (µS/cm)	649	516	581	152	129	438	164	61

Global radiological parameters (b)

Gross alpha activity (Bq/l)	0,14 ± 0,04	< 0,05	0,30 ± 0,10
Gross bêta activity (Bq/l)	0,20 ± 0,03	< 0,03	0,56 ± 0,08
Potassium (mg/l)	2,27 ± 0,10	1,12 ± 0,05	2,08 ± 0,09
Potassium 40 (Bq/l), calculated	0,063 ± 0,003	0,031 ± 0,001	0,057 ± 0,002
Residual Gross bêta activity (Bq/l)	0,14 ± 0,03	< 0,03	0,50 ± 0,08

Uranium (a)

Uranium 238 (µg/l)	0,3	0,76	0,18	0,22	0,47	5 230	42,8	1,45
Calc. U238 activity (Bq/l)	0,003	0,010	0,002	0,003	0,006	65,38	0,535	0,02
Uranium 235 (% uranium 238)	0,74	0,72	nd	0,68	0,70	0,78	0,68	0,72

Radon 222 (c')

Radon 222 (Bq/l)	23 ± 11	< 12	89 ± 23	< 10	< 7	42 ± 17	< 30	< 25

Gamma emitting natural radionuclides (d)

Th 234 (Bq/l)	< 3,3	< 4,2	< 1,5	< 9	< 3,5	63 ± 9	< 3,1	< 1,4
Ra 226 (Bq/l)	< 0,30	< 0,32	detected < 0,7	< 0,30	< 0,31	1,45 ± 0,48	< 0,30	< 0,38
Pb 210 (Bq/l)	< 1,4	< 1,6	< 1,6	< 1,5	< 1,4	< 1,5	< 1,4	< 1,4
U 235 (Bq/l)	< 1,3	< 1,4	< 0,7	< 1,4	< 1,4	5,9 ± 2,1	< 1,4	< 0,8
Pb 212 (Bq/l)	< 0,16	< 0,17	< 0,18	< 0,17	< 0,20	< 0,19	< 0,21	< 0,23
K40 (Bq/l)	< 2,4	< 2,6	< 4,2	< 2,5	< 2,4	< 2,4	< 2,5	< 4,5

Gamma emitting artificial radionuclides (e)

Gamma emitting artificial nuclides (Bq/l)	< DL	< DL	< DL	< DL	< DL	< DL	< DL	< DL

C1 Results of the chemical analysis (metals)

Legend of tables A1, B1 and C1

(a) Analysis conducted by LDA 26 laboratory (France), commissioned by CRIIRAD.

(b) Analysis conducted by EICHROM laboratory (France), commissioned by CRIIRAD.

(c) Radon 222 is monitored using lead 214 and bismuth 214 gamma lines / CRIIRAD laboratory / gamma spectrometry. The volumic activity measured at the laboratory is corrected to sampling time taking into consideration radon 222 natural decay between sampling and counting.

(d) 560 cm3 of water is counted during two to three days in a Marinelli dish on a HpGe gamma spectrometry detector. For Cs 137, some typical detection limits are < 0.04 to < 0.24 Bq/l. All gamma lines are checked on the gamma spectra including the following gamma emitting artificial nuclides : Cs 137, Cs 134, Co 58, Co 60, Mn 54, Ru-Rh 106, I 129, Ce 144, Sb 125, I 131, Ag 110m, Am 241, etc.

(e) 560 cm3 of water is counted during two to three days in a Marinelli dish on a HpGe gamma spectrometry detector. Counting is performed at least 21 days after sealing of the container in order to monitor Ra 226 using restored equilibrium between Ra 226 - Rn 222 - Lead 214 - Bi 214. Normally CRIIRAD laboratory performs these measurements on 10 liters of water. In the present case due to practical limitations it was possible to carry only one liter of liquid. Therefore the detection limits are about 10 times higher than usual. More precise measurements would be requested for a detailed radiological monitoring.

(f) Analysis conducted by LDA 26, commissioned by CRIIRAD (semi-quantitative screening by ICP-MS : inductively coupled plasma – mass spectrometry).

< DL = below detection limit / ND : Not Detected

WHO Guidelines for drinking water are from “Directives de qualité pour l’eau de boisson, OMS 1994” and Guidelines for Drinking-water Quality, WHO, 2008”. And “ Guidelines for Drinking-water Quality, WHO, 2011”.

Figures in red color are exceeding WHO guidelines for drinking water.

Sample Code (on site)	UW1	UW2	UW3	SW1	SW2	SW4	SW3	SW5
CRIIRAD Lab Code	280512A6	280512A7	280512A8	280512A1	280512A2	280512A4	280512A3	280512A5
Location	Drinkable water from a borehole at Kayelekera	Drinkable water from a borehole at Kayelekera	Drinkable water from a borehole at Kayelekera	Sere river upstream path leading to Nkhachira (upstream confluence with Chapwasha river)	Chapwasha river about 150 m from junction with Sere river	"Champhanji" river downstream open pit	Sere river downstream Champhanji river and open pit	North Rukuru river (old bridge) / downstream Sere river
Description	Hand pump close to Primary school	Hand pump close to football ground	Artesian borehole close to secondary school	Surface water (right bank)	Surface water (left bank)	Surface water of a stream	Surface water (right bank)	Surface water
GPS coordinates	S9 57.973	S9 58.211	S9 58.196	S9 58.052	S9 58.255	S9 58.942	S9 59.421	S9 56.620
GPS coordinates	E33 40.939	E33 40.650	E33 41.311	E33 40.866	E33 41.001	E33 42.014	E33 42.422	E33 46.503
Sampling time (local)	22/5/12 13:30	22/5/12 14:15	22/5/12 15:45	20/5/12 14:00	20/5/12 14:40	21/5/12 15:00	21/5/12 12:40	22/5/12 17:20

Métals / semi-quantitative evaluation by ICP (f) / results in µg/l

									WHO guideline for drinking water
Ag	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-
Al	2,39	1,61	0,96	93,3	**449,40**	121,70	64,05	156,90	200 µg/l
As	1,20	0,23	0,44	0,04	0,19	1,59	0,10	0,04	10 µg/l
B	10,68	8,66	10,46	0,00	0,78	8,98	0,06	0,00	300 µg/l
Ba	143	310,5	214,8	27,6	66,7	452,1	43,6	26,74	700 µg/l
Be	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Cd	0,00	0,01	0,00	0,00	0,00	0,03	0,00	0,00	3 µg/l
Co	0,06	0,13	0,00	0,08	0,08	0,07	0,06	0,07	
Cr	0,08	0,00	0,00	0,16	0,42	0,14	0,14	0,21	50 µg/l
Cu	0,38	0,23	0,12	0,25	0,37	0,48	0,30	0,29	2 000 µg/l
Fe	**310,7**	1,16	235,7	96,0	188,7	105,3	58,8	285,7	300 µg/l
Li	53,0	17,64	45,1	0,53	1,54	25,5	0,76	0,22	
Mn	84,2	358,5	52,1	2,36	1,76	6,04	1,99	2,54	500 µg/l
Mo	2,82	1,14	3,27	0,24	0,65	5,59	0,38	0,11	70 µg/l
Ni	0,03	0,06	0,00	0,16	0,31	0,25	0,20	0,13	20 µg/l
Pb	0,02	0,03	0,00	0,02	0,08	0,05	0,04	0,09	10 µg/l
Sb	0,00	0,00	0,00	0,01	0,01	0,02	0,02	0,00	5 µg/l
Se	0,00	0,01	0,00	0,02	0,03	0,30	0,01	0,00	10 µg/l
Sn	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	-
Sr	816,1	482,2	653,1	68,5	102,5	604,70	86,5	45,8	
Te	0,00	0,00	0,00	0,00	0,00	0,00	0,00	0,00	
Ti	6,66	5,87	6,00	7,12	18,96	8,04	5,24	6,41	
Tl	0,00	0,00	0,00	0,01	0,01	0,01	0,00	0,00	
U	0,26	0,76	0,18	0,22	0,47	**5 230**	**42,79**	1,45	15 then 30 µg/l
V	0,03	1,35	0,01	3,02	2,14	1,29	2,77	0,93	
Zn	0,69	3,32	0,14	0,15	0,62	0,33	0,22	0,29	3 000 µg/l

ANNEX 2

Description of solid samples (soil and sediments)

Code	Code	Sampling day	Sampling hour (local time)	Op.	Location	Description of sample	Dry/wet ratio (%)	Gamma radiation flux (c/s) (DG5 scintillometer) Contact soil	Gamma radiation flux (c/s) (DG5 scintillometer) 1m above soil	GPS
280512A9	TS 1	20/05/2012	9H20	CCO-BC	**Kayelekera village** / House of M Charles Sibale near Community Hall	Top soil including dust from regular cleaning of the surroundings of the house	93,6	130	130	S9 58.046 E33 40.969
280512A12	TS 3	20/05/2012	11H40	CCO-WN-BC	In front of house of Kayelekera village's chief at **Nkhachira**	Top soil including dust from regular cleaning of the surroundings of the house	99,1	190	180	S9 59.457 E33 40.428
280512A10	Coal	20/05/2012	10H30	CCO-BC	**Coal mine** inside mine pit (**Nkhachira**)	Freshly extracted coal	92,9	150	140	S10 00.044 E33 40.388
280512A11	TS 2	20/05/2012	11H	CCO-WN-BC	Entrance to **coal mine at Nkhachira**	Radioactive top soil (sand) in a dry drainage area	99,4	390	260	S10 00.044 E33 40.388
280512A13	TS 4	20/05/2012	12H36	CCO-WN-BC	In the middle of the path **from Nkhachira to Kayelekera**	Top soil (dry sand) from the drainage of local sandstone.	99,8	840	500	S9 58.855 E33 40.245
280512A14	SD 1	20/05/2012	14H	CCO-WN	**Sere river** upstream path leading to Nkhachira (upstream confluence with Chapwasha river)	Fine sand under water (right bank)	75	150	130	S9 58.052 E33 40.866
Lost sample	SD 2	20/05/2012	14H40	CC0-WN-BC	**Chapwasha river** about 150 m from junction with Sere river	Fine sand under water (left bank)	NM	110	110	S9 58.255 E33 41.001
280512A16	SD 3	21/05/2012	12H50	CC0-BC	**Sere river** downstream Champhanji river and open pit	Fine grained sediment (1 cm) under water (right bank)	69,6	120	120	S9 59.421 E33 42.422
280512A21	SD 8	22/05/2012	17H25	WN-CCO-BC	**North Rukuru river** (old bridge) / downstream Sere river	Fine sediments (under water)	72,4	150	110	S9 56.620 E33 46.503
280512A20	SD 7	21/05/2012	15H30	CC0-BC-WN	dry stream immediately north of "Champhanji" river , below the open pit	fine grained sediment including clay (dry, 1 mm)	98,6	220	200	S9 58.832 E33 41.982
280512A19	SD 6	21/05/2012	14H50	CC0-BC-WN	**"Champhanji" river** below the open pit	fine grained sediment including clay (under water)	72,5	650	530	S9 58.942 E33 42.014
280512A17	SD 4	21/05/2012	13H26	CC0-BC	Dry stream on the eastern slope of Paladin mine	Dry sediment (sand and clay)	96,6	550	450	S9 59.266 E33 42.262
280512A18	SD 5	21/05/2012	13H40	CC0-BC-WN	Disturbed and radioactive area on the esatern slope of Paladin mine lease	Dry material at the bottom of a drainage area (clay)	94,3	950	750	S9 59.205 E33 42.215

ANNEX 3

Description of the counting conditions of the solid samples (soil and sediments)

Code	Sampling day	Location	Description of sample	SPP2 (c/s)	Counting Geometry	Weight (dry)	Analysis N°
TS 1	20/05/2012	**Kayelekera village** / House of M Charles Sibale near Community Hall	Top soil including dust from regular cleaning of the surroundings of the house	45	P	90,8	C 26841
TS 3	20/05/2012	In front of house of Kayelekera village's chief at **Nkhachira**	Top soil including dust from regular cleaning of the surroundings of the house	45	P	110,61	C 26843
Coal	20/05/2012	**Coal mine** inside mine pit (**Nkhachira**)	Freshly extracted coal	40-45	P	63,14	C 26845
TS 2	20/05/2012	Entrance to **coal mine at Nkhachira**	Radioactive top soil (sand) in a dry drainage area	50-55	P	96,91	C 26839
TS 4	20/05/2012	In the middle of the path **from Nkhachira to Kayelekera**	Top soil (dry sand) from the drainage of local sandstone.	105	P	110,98	B 26866
SD 1	20/05/2012	**Sere river** upstream path leading to Nkhachira (upstream confluence with Chapwasha river)	Fine sand under water (right bank)	45	P	74,12	C 26859
SD 2	20/05/2012	**Chapwasha river** about 150 m from junction with Sere river	Fine sand under water (left bank)				
SD 3	21/05/2012	**Sere river** downstream Champhanji river and open pit	Fine grained sediment (1 cm) under water (right bank)	45-50	P	77,52	C 26848
SD 8	22/05/2012	**North Rukuru river** (old bridge) / downstream Sere river	Fine sediments (under water)	45	P	74,15	C 26847
SD 7	21/05/2012	dry stream immediately north of "Champhanji" river , below the open pit	fine grained sediment including clay (dry, 1 mm)	50	P	76,86	B 26869
SD 6	21/05/2012	**"Champhanji" river** below the open pit	fine grained sediment including clay (under water)	70-75	P	79,85	B 26875
SD 4	21/05/2012	Dry stream on the eastern slope of Paladin mine	Dry sediment (sand and clay)	45-50	P	82,06	C 26857
SD 5	21/05/2012	Disturbed and radioactive area on the esatern slope of Paladin mine lease	Dry material at the bottom of a drainage area (clay)	65	P	76,09	B 26873

ANNEX 4

Controlled discharge of liquid effluents

Paladin has provided some information about the project of discharge of liquid effluents to the Parliamentary Committee for Natural Resources and Climate Change in October 2014. The website “Miningmalawi.com” gives details of the presentation given by M. David Holmes, Group Principal Hydrogeologist from PAL. See below :

“With the onset of the rains, the controlled release of water is necessary to prevent the storage ponds (Runoff Water Pond 1 and 2) from reaching capacity and overflowing. The Tailings Storage Facility will not overflow as evaporation exceeds inflow”.

“On 30 July 2014, Paladin Africa applied for a licence from the Government of Malawi to discharge treated water from the mine into the local river system during the next two or three wet seasons, depending on how long the mine remains on care and maintenance. The Water Resources Department provided guidance and the National Water Resources Management and Development Committee met on 16 September 2014 to assess the application. Their recommendation was approved by the Minister on 22 October 2014.”

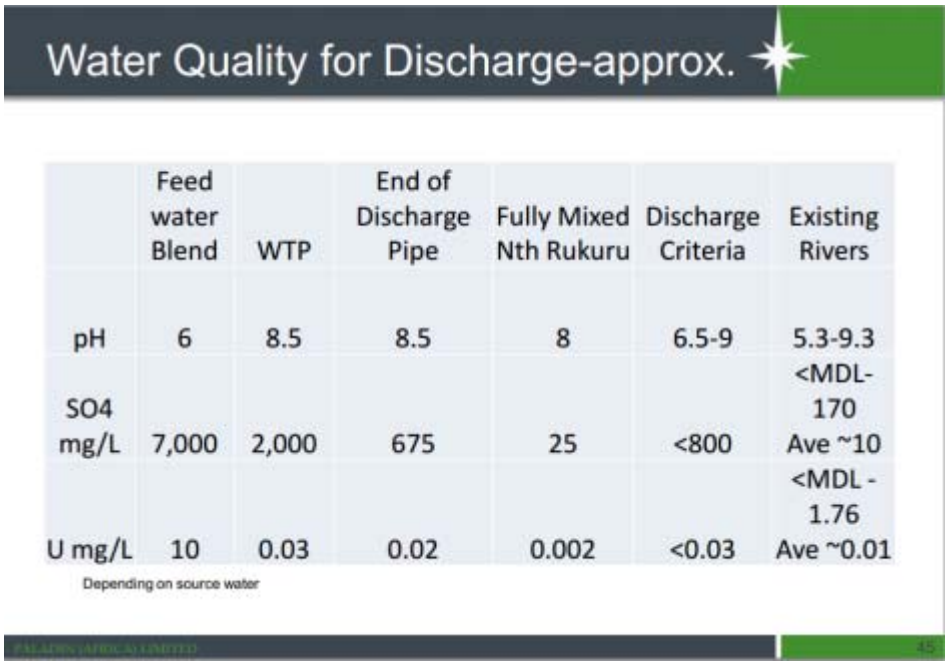
“Laboratory trials commenced in March 2014 and produced favourable results including the removal of uranium. In July, a full scale water treatment plant was set up. Holmes explained that the treated water will meet the licensed discharge criteria that are based on the Malawian regulatory requirements for discharge into inland waters (Malawi Standard MS539; 2002) and conform to international guidelines”.

“The image below indicates the pH, sulfate and uranium levels at the end of the discharge pipe and after being diluted with water from the North Rukuru River”.

Fig. 59

Water Quality for Discharge, Kayelekera Uranium Mine Water Treatment Plant (WTP)

Source: Paladin Africa presentation at Extraordinary DEC Meeting, Karonga, 28 October 2014



"Below is an overview of some of the information presented by Paladin:

- Treatment and discharge of up to 450,000 cubic metres per year. This is less than 0.3 per cent of the long term average volume of water that naturally flows down the North Rukuru River.
- World Health Organisation (WHO) guideline for uranium in drinking water of 0.03 mg/litre will be met. WHO states that the "guideline value is designated as provisional because of scientific uncertainties surrounding uranium toxicity".
- Sulfate concentration will be no more than 800 mg/litre of water. WHO does not provide a guideline value because "existing data do not identify a level of sulfate in drinking-water that is likely to cause adverse human health effects" although concentrations of 1000-1200 mg/litre indicate a laxative effect but no increase in diarrhoea, dehydration or weight loss. WHO emphasises that health authorities should be notified of sources of drinking water that contain sulfate concentrations in excess of 500 mg/litre. The presence of sulfate in drinking water may cause noticeable taste at concentrations above 250 mg/litre and may contribute to the corrosion of distribution systems.
- Monitoring conducted by mine's Environment Department with Government's Water Resources Department accompanying on sampling events. In addition, the Environmental Affairs Department will independently sample and test water to ensure compliance. Samples will be analysed by internal and external laboratories for the water treatment plant at 13 locations upstream and downstream of the discharge point. Four hourly analyses of critical parameters of uranium and sulfate in the water treatment plant and four analyses of key parameters per day in the discharge line to the Sere River at three locations for

- pH
- Electrocoagulation
- Total suspended solids
- Calcium
- Sulfate
- Uranium
- Radium-226
- Chemical oxygen demand
- Dissolved oxygen

- Uranium already in the district. An extensive data set collected since 2006 shows that there are naturally occurring uranium levels in the Sere River that have ranged up to 1.76 mg/litre on occasion and values in the range of 0.15-0.3 mg/litre are not uncommon. The mine pit ground water discharges are naturally high in uranium and historically discharged via the Champhanje Stream and natural springs, while natural groundwater in the pit area can be up to 100 mg/litre, currently around 30 mg/litre.
- Automatic shutdown of plant if any deviation from the discharge criteria is recorded. In the event of any such deviation, the process allows for water to be recycled for further processing."

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