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CRIIRAD preliminary report N° 19-28 (DRAFT)

Monitoring in the Environment of the INB uranium mine in Caetité (Brazil, BA)

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1 / Context

The Federal University of Bahia (UFBA) has asked the laboratory of CRIIRAD (Commission for Independent Research and Information on Radioactivity) to provide scientific support for a preliminary study on the impact of uranium mining activities performed by the company **INB** (Indústrias Nucleares do Brasil), about thirty kilometers north-east of the city of **Caetité** (state of Bahia).

1-1 / Description of the INB site

The main sectors of the industrial site are:

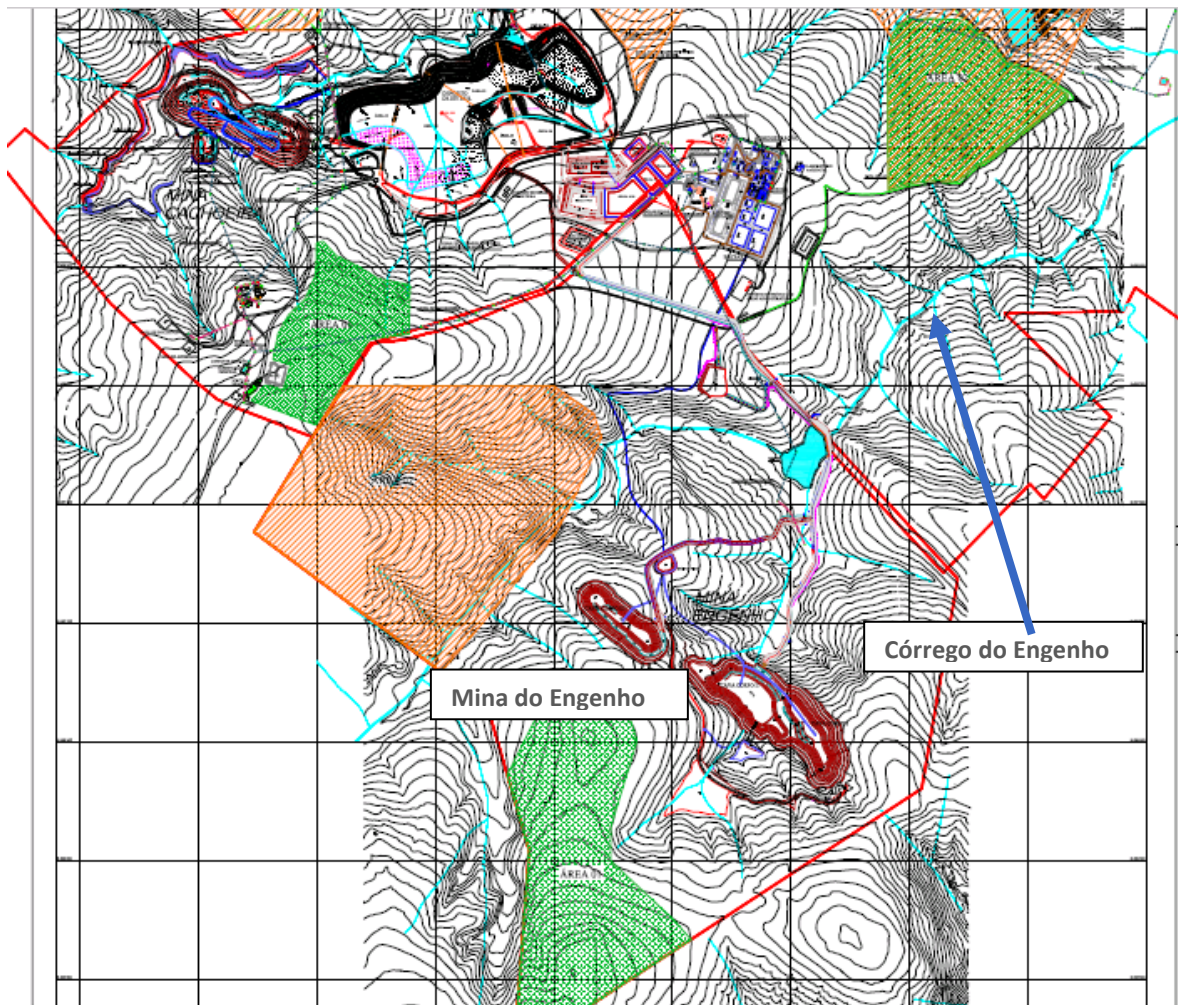
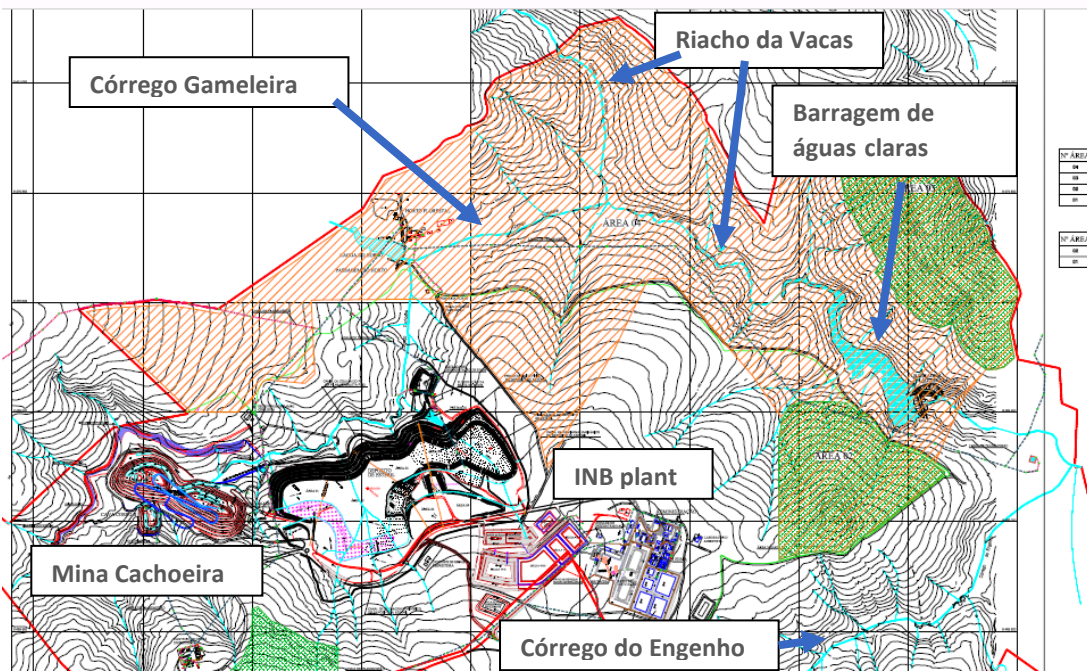
- The **Cachoeira open pit**. This mine is no longer in operation.
- The uranium ore crushing area
- The piles where the leaching process takes place.
- The chemical plant for uranium extraction from leach liquids and production of uranium concentrate ("yellow cake").
- The **waste rock piles** containing also the radioactive **tailings**, that is, the solids that have undergone the leaching process. An important part of the uranium has been extracted. But more than 80% of the initial radioactivity of the uranium ore is remaining in the tailings due to the presence of the main radioactive decay products of uranium such as thorium 230, radium 226, lead 210, etc.
- The areas of management of the liquid effluents.

The areas described above constitute the "historic" industrial site. It is located on a plateau surrounded by two main watersheds:

- To the north, the **córrego Gameleira** (called Riacho Mangabeira in some documents) which joins the **Riacho da Vacas** downstream the "Horto Florestal". These waters feed the artificial dam called "**Barragem de águas claras**" (see picture 1, next page).
- To the East, the **córrego do Engenho** that joins the Riacho da Vacas upstream of the place called Bela Vista. In the upper part of the córrego do Engenho watershed, a new open pit uranium mine is being implemented (**Mina do Engenho**, see picture 2, next page).

Maps extracted from the authorization file for the creation of the new mine are reproduced on the following pages.

Pictures 1 and 2 / INB industrial site and main water sheds
(source : INB, licenciamento da mina do Engenho, 2014)



1-2 / Objectives and progress of the mission

The mission was conducted from November 7 to 14, 2018.

Initially, it was planned that most of the field work would be devoted to carrying out measurements inside the INB industrial site. But the authorization was not obtained on time. The objectives of the mission had to be reviewed. They comprised:

- Discussions with **uranium workers** (current and former workers) and **residents** living near the mine. These discussions took place especially in Caetité, Gameleira, Pega Bem, and Bela Vista.
- **Collecting workers' hair** for analysis of the uranium content (these results are presented in the CRIIRAD report No. 19-03).
- **Meeting with the prosecutors** in charge of examining complaints about the health and environmental impact of uranium mining activities. Mr. Carlos Vítor de O. Pires (Procurador da República em Guanambi, Ministério Público Federal), was met on November 7, 2018 and Mr. Erik de Sousa Oliveira (Procuradoria do Trabalho no Município de VITÓRIA DA CONQUISTA, Ministério Público do Trabalho), on November 14, 2018.
- Examination of the documents associated with some of these complaints, in particular the **reports** describing the measurements made by INB on its industrial site and in the environment. The days of 7 and 8 November were devoted to examining these documents, in Guanambi, in the offices of the public prosecutor.
- **Independent monitoring activities** in the environment. This mission included monitoring of **gamma radiation levels** at the soil surface, as well as collection of samples of **water** and solids (**soil and sediments**).

As the main industrial site and the new mine (Mina do Engenho) were fenced, measurements and sampling could only be carried out in the external environment.

During the mission, the gamma radiation flux was measured using a **gamma scintillometer**, Model DG5, brand Novelec. This is a very sensitive device used to identify radiation anomalies and to select sampling sites. The results are expressed in **counts per second (c/s)**. This device has been used systematically during walking trips along roads, paths, dry rivers, etc ... More than one hundred measurements have been made. Only the most significant ones are discussed in this report.

Priority was given to inspecting streams and their banks for **sediment**. Sediment analysis is of interest because radioactive substances in the water are likely to settle and accumulate in sediments. The sediment analysis then makes it possible to provide information over periods of several years. Given the limited duration of the mission, interruptions related to heavy rainfall and difficulty of access to watercourses (fences, roads in very bad condition), the work done here has only an exploratory character.

A total of **11 sediment samples** were collected, plus **6 other solid samples** corresponding to areas that had a higher ground contact gamma radiation level than the local background.

Special attention has been given to identifying the most appropriate wells or boreholes for independent **water sampling**. These are piezometers located downstream the INB industrial site.

In the area north of the waste rock dumps (Horto Florestal sector), the piezometers are not accessible.

In the lower part of the Riacho da Vacas, downstream of the “Barragem de águas claras”, we retained borehole PC 12 (depth – 40 meters) at Bela Vista because it is located immediately at the confluence between the Riacho da Vacas and the córrego do Engenho. Underground water samples were also collected at PC 5 and in a private artesian well at Pegam Bem (sample UWA 3). Two additional samples of underground water were collected near the locality of Gameleira (water from PC 171 and from an Amazonian well).

Field measurements and sampling took place on:

- **9 November:**
Radiation monitoring and sampling of soil (**TS 16**) and sediments (**S5, S12**) in the area close to the confluence between the córrego do Engenho and the Riacho da Vacas (to the East of the industrial site).
Search for piezometers and access tracks on the right bank of the córrego do Engenho.
- **10 November:**
Radiation monitoring and sampling of sediments in the córrego Gameleira (**S6**, upstream the place called “Horto Florestal”), in a drainage area in a valley located north of the industrial site (**S8**), and in the Riacho da Vacas sector (**S7**, upstream and **S9**, downstream the confluence with the córrego Gameleira, north of the industrial site. Samples S6 and S7 can be considered representative of local natural background.
Sampling of material with an elevated radiation rate (**TS 24**) in the river bed of the Riacho da Vacas.
Sampling of soil with slightly abnormal radiation rates on the track leading to the Cachoeira mine (**TS 20**) and near the entrance of the “Horto Florestal” (**TS 19**).
Sampling of soil (**S1, S2**) on the main road, south of the Engenho mine (hot spot).
- **11 November:**
Radiation monitoring and sampling of underground water in the hamlet of Gameleira (**UWA 1 : PC 171**) and at a place called “Baixa da Onça” (sample **UWA 2**), west of the industrial site, in areas subject to intense prospecting activities. The realization of the measurements at Baixa da Onça was recorded on video support.
- **12 November:**
Sampling of underground water at **Pega Bem (UWA 3)** and **Bela Vista (UWA 4; UWA 5)**, to the east of the INB industrial site.
Radiation monitoring and sampling of sediments in the Riacho da Vacas (**S10**, upstream the dam called “Barragem de águas claras”, **S11**, inside the dam (along with surface water **SWA 1**), and **S13**, downstream from the confluence with the córrego do Engenho).
Radiation monitoring in several sectors of the córrego do Engenho bed downstream of the future Engenho open pit mine and sampling of sediments (**S4**) and surface water (**SW A2**) in an artificial lake temporarily created by heavy rain.
Monitoring of radiation and sampling of sediments (**S3**) in an area with high radiation readings south of the fence of the Engenho mine. The realization of these measurements was recorded on video support.

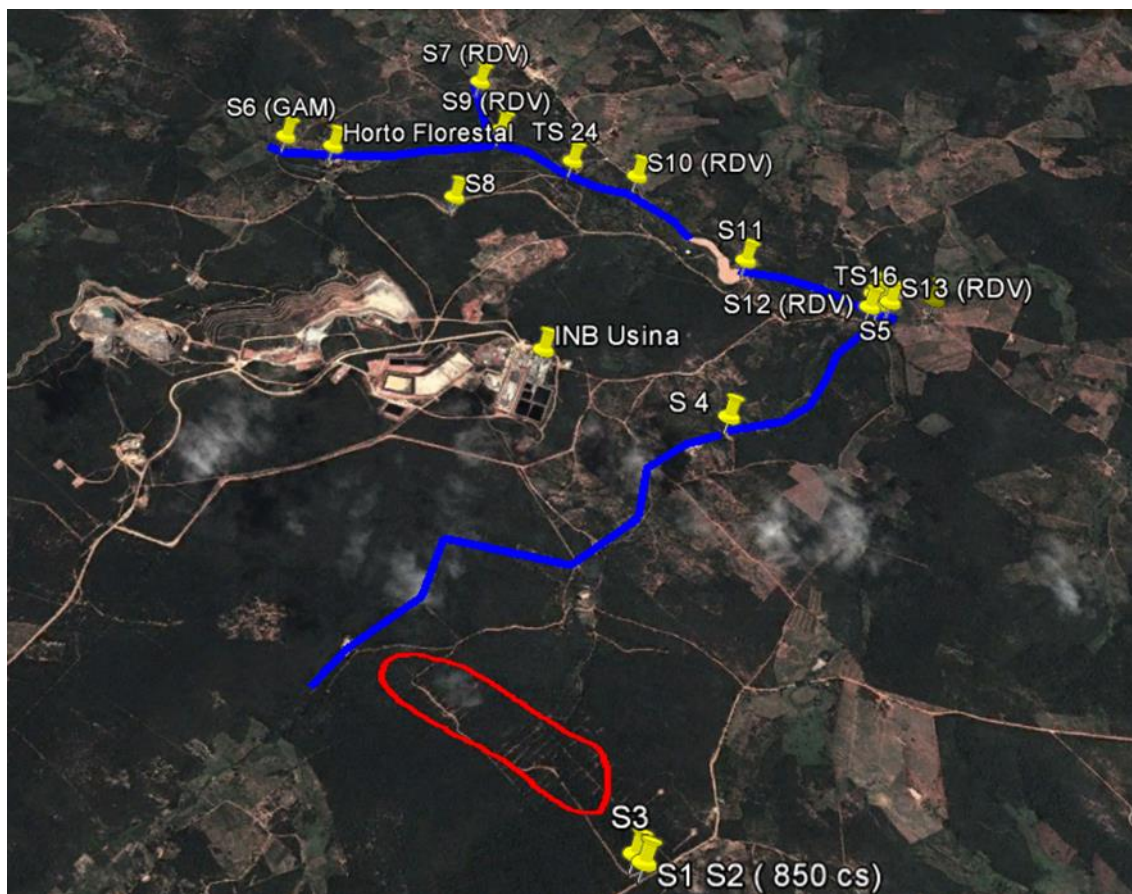
The location of the main samples of solids is shown on picture 3, next page.

The results of the analysis performed on the samples are reproduced in **Appendix 1 (water)** and **2 (samples of soils and sediments)**. For solid samples, are also given in Appendix 2 the results of monitoring of gamma radiation at the sampling collection point.

During the first part of the mission, the majority of the river beds were dry. Measurements of radioactivity could be made directly in the bed. But heavy rains fell in particular on November 10,11 and 12 during the afternoon, which made the field mission more difficult.

Due to administrative problems, the budget allocated to the CRIIRAD laboratory has been reduced by more than 25%. The engineer's working time initially allocated to writing the scientific report has been reduced to zero. CRIIRAD has however decided to publish in this preliminary report all the results of the analyzes of the samples brought back. Their detailed interpretation and the critical analysis of the documents examined on the spot cannot be carried out however within the framework of this report.

Pictures 3 / Sampling along the córrego Gameleira, Riacho da Vacas and córrego do Engenho
(Satellite view: Google Earth, year 2013)



2 / Main findings (Preliminary report)

2-1 / General notions about “natural” levels of radiation

Activity expressed in Becquerels (Bq/kg)

The earth's crust and consequently the soils and sediments naturally contain so-called "telluric" radionuclides.

These are potassium 40, uranium 238, uranium 235 and thorium 232. The last 3 give rise to disintegration chains.

Uranium 238 is associated with 12 radioactive metals (such as thorium 234, thorium 230, radium 226, lead 210) and a radioactive gas (radon 222). All these radioactive substances are permanently created by the disintegration of uranium 238.

The amount of radioactive material, the so called “activity”, is expressed in Becquerels (Bq). Usually Bq/kg for solid samples, Bq/l for water; Bq/m³ for the air. One Becquerel means one disintegration of a radioactive substance per second.

The typical activity of Uranium 238 and Thorium 232 in the soil is about¹ 40 Bq/kg.

In fact the natural variability of the concentrations of these radionuclides in the soil is very significant. It is depending on the geological properties of the rocks.

Level of gamma radiation at the soil surface

The disintegration of uranium-238 and its thirteen radioactive decay products (including radium-226) leads to the emission of alpha, beta and gamma radiation. Gamma radiation is the most penetrating one, which is why gamma scintillometers are used for prospecting activities.

Even without any anthropic contamination, the natural value of the gamma flux at the soil surface may have significant variations depending mainly on the amount of natural radionuclides of telluric origin (U-238, Th-232, and K-40).

The “normal” gamma radiation rate at the surface of the soil around the INB mine appeared to be typically between **110 c/s and 250 c/s**. But much higher values were observed at some locations.

2-2 / Impact of uranium prospection

As indicated above, the typical activity of uranium 238 in a “normal” soil is of the order of 40 Bq/kg. It can be about 200 Bq/kg in typical samples of granite rocks.

But when one is in the presence of **uranium deposits**, the uranium 238's activity can reach several thousand or even tens of thousands of Becquerel per kilogram. If the uranium ore is buried deep in the ground, the radiation it emits does not reach the surface and there are conventional radiation levels at the soil surface. When the deposit is close to the surface, the level of radiation can increase sharply. In some cases the deposits are outcropping naturally which creates “hot spots”.

But human activities can lead to increased levels of ambient radiation, as is the case when the protective layer of soil that naturally covered the uranium-rich rocks is removed.

This may be the case during earthworks and when companies carrying out prospecting work make trenching exploration or implement drills. At the end of prospecting operations, if the covering soils are

¹The 1982 UNSCEAR (United Nations Scientific Committee on the Effects of Atomic Radiation) report proposed to use the values of 370, 25 and 25 Bq/kg for the average activities of the K-40, U-238 and Th-232 elements in soils on a global scale. In view of the higher results reported for China and the USA, the UNSCEAR 1993¹ report has revised upwards to 40 Bq/kg for U-238 and Th-232. UNSCEAR 2000 report has the following median values: 400, 35 and 30 Bq/kg, respectively for K-40, U-238 and Th-232 on a global scale.

not put back in place, the radioactive rocks are exposed to the surface which leads to an increased exposure of the population to ionizing radiation.

Such situations were identified during the mission:

Example 1 / South of Engenho uranium mine

On the road, south of the prospecting area of the future Engenho mine, a high level of radiation was detected in the vehicle. A prospecting on foot allowed to locate the radiating sector.

In contact with the ground, in the middle of the road, the gamma radiation flux rises to **850 c/s** (sector S1 on the map below). This value is more than 3 times higher than the local background.

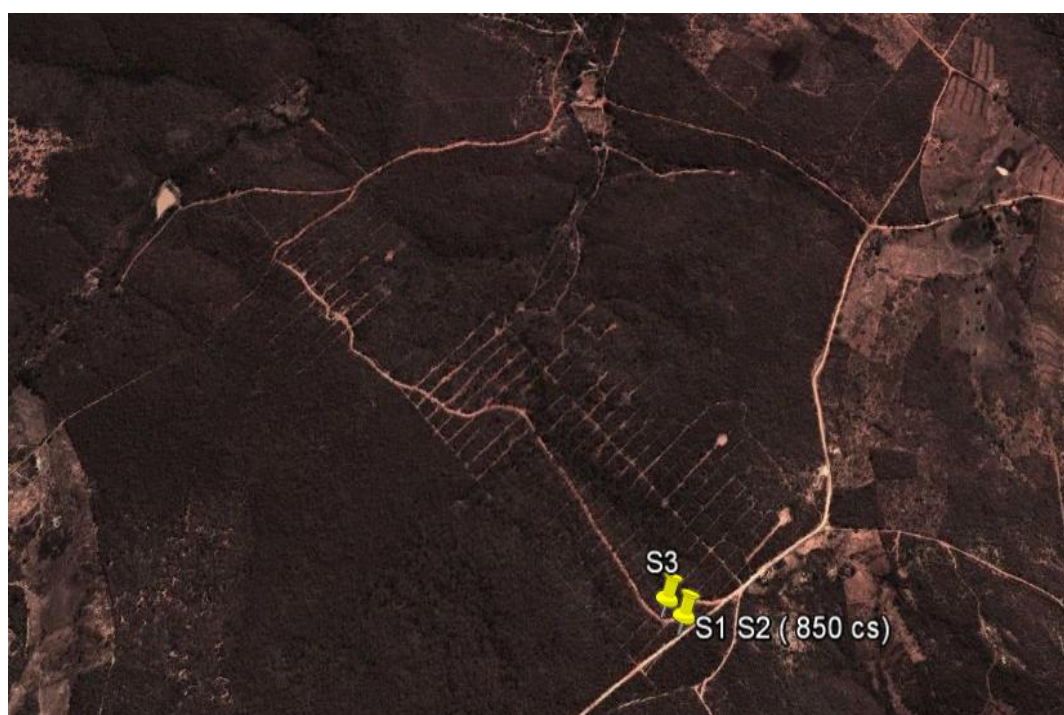
The activity of radium 226 in the first 3 cm of soil is **115 Bq/kg** (sample S1), but it reaches **1,040 Bq/kg** in the 3-7 cm horizon (sample S2). This shows that the uranium deposit is close to the surface.

This area has been submitted to intense uranium prospection activities as illustrated by the satellite picture below. The light colored bands on picture 4 correspond to areas that have been cleared for prospecting and where tracks and trenches have been dug. At present, as shown on picture 5, the open pits are being created.

These activities facilitated the exposure of the uranium veins (depletion of the upper layer of soil, increase of erosion) and led to an increase in the level of radiation. Thus, when leaving the main road and walking towards the fence of the mine, an area (**S3**) was identified where the **radioactive rocks were exposed** (pictures 6-8).

The gamma radiation rate on contact with the rocks reaches **2 700 c/s**. It remains high even at 1 meter above ground: **1 300 c/s**, which is equivalent to a doserate of **1,07 μ Sv/h**. This means that by staying every day for less than two minutes on this place, the cumulative annual dose exceeds the value of 10 microSieverts per year considered by the European authorities as the limit beyond which the risks are no longer negligible and measures of radiation protection must be implemented. For a cumulative duration of 1 200 hours in the year, the maximum permissible annual dose of 1,000 microSieverts per year may be exceeded.

Picture 4 / Area submitted to intense prospection activities before the opening of the Engenho uranium mine (Source : GoogleEarth, satellite view : year 2013)



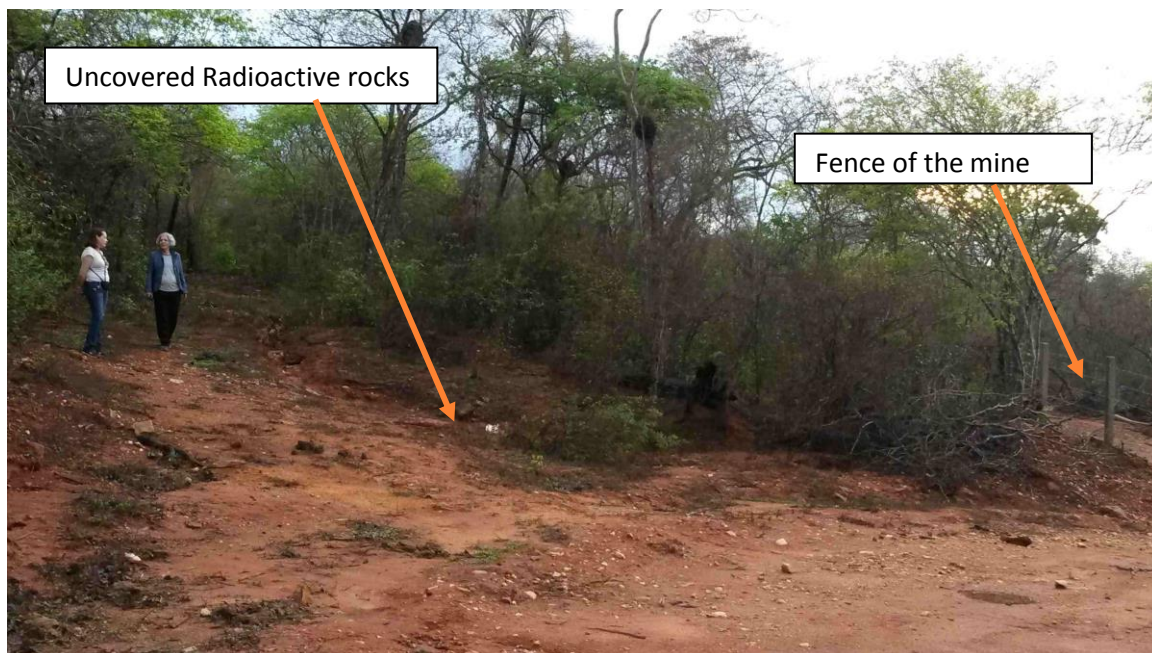
Picture 5 / Preparatory works for the opening of the Engenho uranium mine (Source: GoogleEarth, satellite view : year 2018)



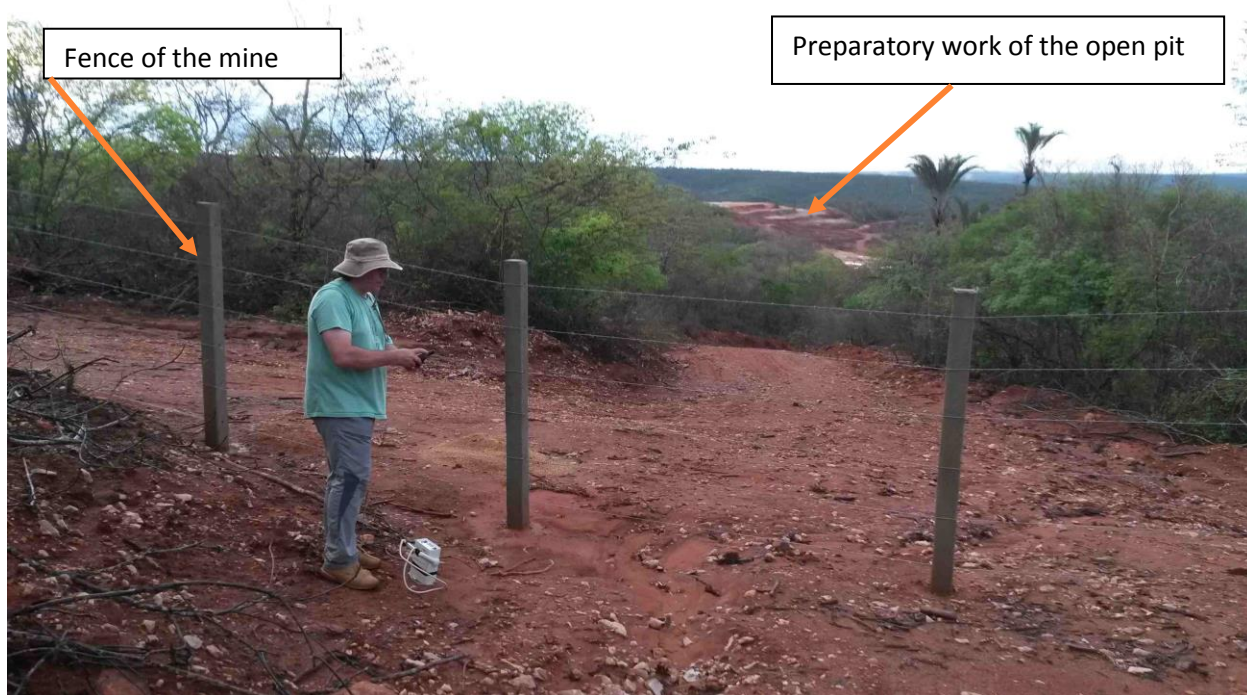
The fact that radioactive rocks are exposed to the rain increases the risk of transfer of radioactive substances to the environment.

Thus, the sediments S3 taken a few meters down from the uranium vein show a radium-226 activity of **410 Bq/kg**, a value 6 times higher than that measured in the sediments S7 taken from the Riacho da Vacas. Sample S7 can be considered as representative of a natural situation, being located outside the influence of potential leakage from the industrial site of INB.

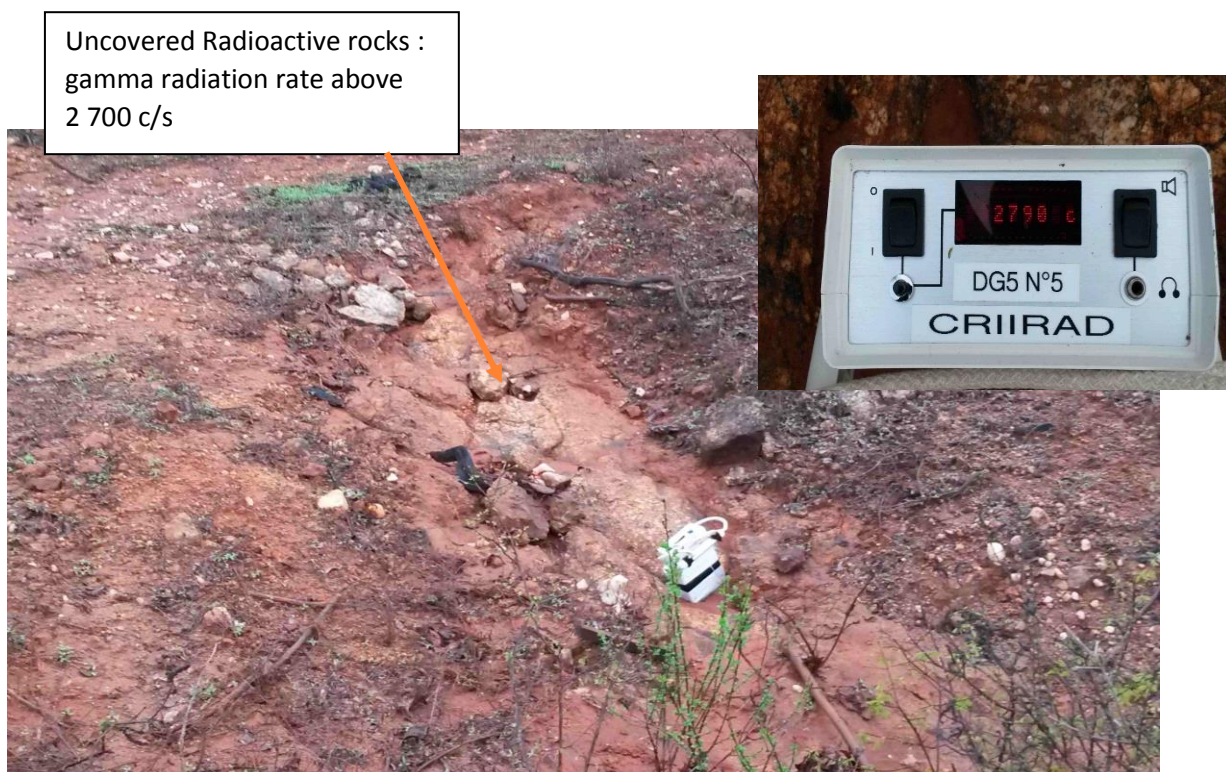
Picture 6 / Area submitted to intense prospection activities near Engenho mine (Source : CRIIRAD)



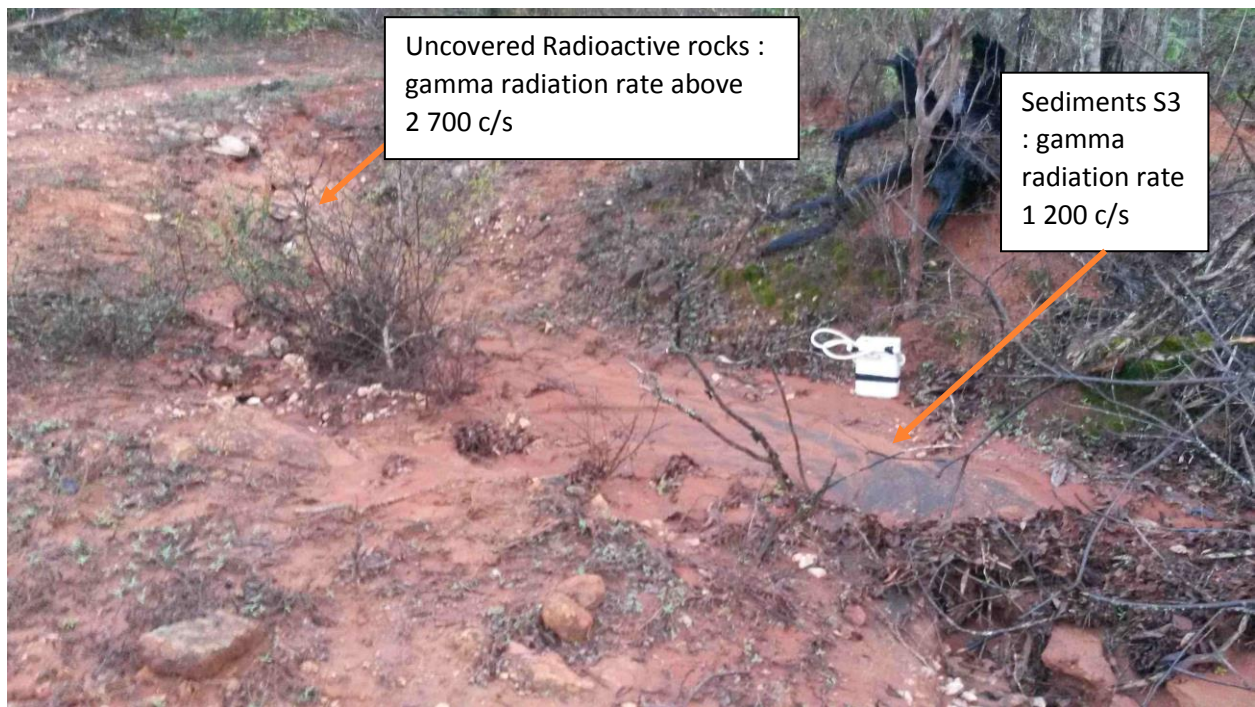
Picture 7 / Area submitted to intense prospection activities near Engenho mine (Source : CRIIRAD)



Picture 8 / Area submitted to intense prospection activities near Engenho mine (Source : CRIIRAD)



Picture 9 / Sediments S3 collected below the radioactive uncovered rocks (Source : CRIIRAD)



Example 2 / Gameleira, area of the Baixa da Ronça

North of the hamlet of Gameleira, prospecting work was conducted quite recently on both sides of the track leading to the Amazonian well of Baixa da Ronça.

This work obviously consisted in the realization of trenches, exploratory pits, deep drilling (some drills reach a depth of 60 meters). At the end of their work, the prospectors have left a completely ravaged ground.

As the 11th November photographs below show : the upper parts of the drill pipes are in the open air (picture 12), and are sometimes broken (picture 17), which promotes the emanation of the radioactive gas emitted by the decay of uranium; the earth is exposed on large areas (pictures 13, 16), which strengthens the erosion mechanisms (picture 13) and puts the materials rich in uranium in direct contact with the surface.

Thus, over the entire area disturbed by the work, there are high levels of radiation: **800 c/s** at the foot of a cement bollard, **1 300 c/s** at the foot of a trench (picture 18), **6 400 c/s** on the edge of the track (picture 10 and 11).

There, the gamma radiation rate still reaches **2 700 c/s** at 1 meter high. This is equivalent to a dose rate of **2.2 $\mu\text{Sv/h}$** . This means that by staying every day for two minutes on this path, the cumulative annual dose exceeds the value of 10 microSieverts per year considered by the European authorities as the limit beyond which the risks are no longer negligible and measures of radiation protection must be implemented. For a cumulative duration of 500 hours in the year (1 hour and 21 minutes per day), the maximum permissible annual dose of 1,000 microSieverts per year may be exceeded.

Such a situation is not acceptable. It illustrates the lack of training of drilling companies on the risks associated with ionizing radiation.

Exploration work has increased surface radiation levels and leads to an increase in the risk of transfer of radioactive elements to the environment and to humans in the long term, both the risks associated with the emanation of the radon and inhalation of radioactive dusts and the risk of contamination of water resources through increased erosion and facilitated transfer of radioactive heavy metals contained in the soil. Not to mention the risk that people are using these radioactive lands as building material or are planning to grow crops there.

Picture 10 / Area submitted to intense prospecting activities: track leading to Baixa da Ronça
(Source : CRIIRAD)



Picture 11 and 12 / Area submitted to intense prospection activities: gamma radiation rate above 6 600 c/s and open borehole on the track leading to Baixa da Ronça (Source : CRIIRAD)



Picture 13 / Area submitted to intense prospection activities: increased erosion above the track leading to Baixa da Ronça (Source : CRIIRAD)



Pictures 14 and 15 / Area submitted to intense prospection activities: disturbed land above the track leading to Baixa da Ronça (Source : CRIIRAD)



Pictures 16-17-18 / Area submitted to intense prospection activities: disturbed land, broken pipes, hot spot at the bottom of a trench above the track leading to Baixa da Ronça (Source : CRIIRAD)



Trench (see picture 18 below)



Impact of uranium prospecting activities on the quality of water resources

In the case of the hamlet of **Gameleira**, numerous drills have been implemented in the fields, during the years 2012-2013, in order to reach the uranium deposits. Some are reaching a depth exceeding 100 meters.

The company INB has also drilled a borehole (**PC 171**), at a depth of 64 meters, in the valley located below the prospected area. When CRIIRAD monitored the water of PC 171 in April 2014, the uranium concentration was **11.5 µg/l**. In the sample collected in November 2018 (UWA 1), the concentration of uranium has reached **104,7 µg/l** which is a **9 fold increase**. This value is well in excess of the 15 µg/l potability limit in force in Brazil.

Examining the April 2014 and November 2018 analysis results (see Table 1 on the following page), we find that most of the other measured parameters are stable with the exception of **strontium** and **manganese** (3-fold increase), **selenium** (increase by a factor of 4) and **molybdenum** (increase by a factor of 36). These results suggest that uranium exploration activities have altered groundwater characteristics and facilitated the migration of some toxic metals.

In order to reinforce this hypothesis it is necessary to obtain from INB all of the groundwater measurement results and to continue to carry out independent measurements.

In the case of **Baixa da Ronça**, the water of the Amazonian well has a very low uranium concentration (**0.8 µg/l**, sample UWA 2). This well is located upstream the area affected by the prospecting.

It is desirable that specific drilling be implemented to monitor the evolution of groundwater radioactivity downstream of the area disturbed by uranium prospecting at Baixa da Ronça.

To be continued in the final report :

2-3 / Radioactivity of reused materials for backfilling of runways and watercourse crossings

2-4 / Discussion on the impact of overflows of the retention pond for fine materials downstream of the waste rock dump

2-5/ Interpretation of sediment analysis results

2-6 / Interpretation of surface water test results

2-7 / Interpretation of groundwater test results

2-8 / Discussion on radioactive dust emissions

2-9 / Discussion on exposure to radon gas 222

2-10 / Discussion on dosimetric monitoring of workers

Conclusion

Table 1 / Characteristics of the water sampled by CRIIRAD at PC 171 in Gameleira in April 2014 and November 2018

Sample Code (on site)	UW3 (PC 171)	UWA 1 (PC 171)
Sampling day	09/04/2014	11/11/2018
pH	7.3	7.0
Conductivity at 25 °C (µS/cm)	979	1 431
Conductivity at 20 °C (µS/cm)	883	1 291
T.A.C (degré français)	21	22.7
T.A. (degré français)	< 2	< 2
Uranium 238 (µg/l)	11,5	104,7
Radon 222 (Bq/l)	107 ± 41	140 ± 20
Bicarbonates (Hydrogénocarbonates) mg/l	256,2	276.9
Calcium mg/l	18	34
Chloride (chlorures) mg/l	65	168
Magnesium mg/l	5,7	10,0
Nitrates mg/l	180	238
Nitrites mg/l		0,021
Potassium mg/l	2,1	5.2
Sodium mg/l	200	254
Sulfates mg/l	44	50

Metals / semi-quantitative evaluation by ICP * / results in µg/l

Ag	0,00	0
Al	77,3	15
As	0,00	0
B	86,80	48.6
Ba	97,90	118.1
Be	0,30	0
Cd	0,00	0
Co	0,90	0.6
Cr	1,00	0.4
Cu	7,70	4.8
Fe	88,40	26.9
Li	20,50	24
Mn	17,20	57.3
Mo	0,24	8.8
Ni	1,80	4.2
Pb	5,40	0
Sb	0,00	0
Se	0,40	1.7
Sn	0,00	0
Sr	65,10	167.3
Te	0,00	0
Ti	12,70	9.7
Tl	0,00	0
U	11,50	104.7
V	20,3	7,0
Zn	6,90	NM

Appendix A1 / Analysis of underground water samples (UW) and surface water samples (SW) (2 pages)

Sample Code	UWA 1	UWA 2	UWA 3	UWA 4	UWA 5	SWA 1	SWA 2
Sampler	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)
Location	Borehole PC 171 in Gameleira downstream uranium prospection area, installed by INB (2013)	Baixa da Onça near Gameleira	PEGA BEM , right bank of Riacho da Vacas : (downstream INB facilities)	Bela Vista. PC 12 (downstream INB facilities)	PC 5 Located in a stream on the left bank of Riacho da Vacas valley.	Barragem de aguas claras	Dam in the Corrego do Engenho , downstream the mine and the INB uranium concentration
Water type	Underground water (depth 64 m) / collected at the outlet near the house / no more used for drinking	Amazonian Well , depth 6 m, used for cattle and irrigation	underground water (-60 m), collected in the tank. Used for cooking	underground water (-40 m) / collected at the pipe before the tank / used for cattle and irrigation	underground water / collected at the pipe before the tank / used for cattle and irrigation	Surface water,	Surface water, during high rainfall
GPS coordinates	13,84477	13,84348	13,83294	13,83251	13,82619	13,82948	13,8387
GPS coordinates	42,31784	42,32724	42,25351	42,25673	42,25747	42,26667	42,26842
Sampling day	11/11/2018	11/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018

pH and conductivity (laboratory measurements)

pH	7.0	5.2	7.2	7.1	7.0	7.7	5.9
Water T°C when pH was measured	18.2	17.8	17.5	17.8	18.1	18.3	18.7
Conductivity at 25 °C (µS/cm)	1 431	444	1 250	1 007	646	219	49
Conductivity at 20 °C (µS/cm)	1 291	400	1 128	908	583	198	44
T.A.C (degré français)	22.7	< 2	22.4	32.7	20.4	5.7	< 2.0
T.A. (degré français)	< 2	< 2	< 2	< 2	< 2	< 2	< 2

Uranium

Uranium 238 (µg/l)	104,7	0,8	9,3	20,0	2,4	0,3	4,8
Calc. U238 activity (Bq/l)	1,31	0,01	0,12	0,25	0,03	0,00	0,06
Uranium 235 (% uranium 238)	0.68	0.72	0.71	0.70	0.71	0.74	0.73

Radon 222

Radon 222 (Bq/l)	140 ± 20	15 ± 6	25 ± 10	41 ± 7	32 ± 9	< 20	< 10
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Ammonium mg(NH4)/l	0.13	0.15	0.14	0.14	0.10	0.17	0.13	WHO guideline for drinking water	
Bicarbonates (Hydrogénocarbonates) mg/l	276.9	< 24	273.3	398.7	249.2	69.5	< 24		
Calcium mg/l	34	9.1	77	76	40	13	4.1		
Chloride (chlorures) mg/l	168	130	194	99	61	26	< 2.0		250 mg/l
Magnesium mg/l	10,0	2.6	14	11	3.2	3.7	< 2.0		< 2.0
Nitrates mg/l	238	1	98	18	12	< 2.0	2.8		50 mg/l
Nitrites mg/l	0,021	< 0.01	0,014	< 0.01	0,022	< 0.01	0,231		0,5 mg/l
Potassium mg/l	5.2	1.2	13,0	9.4	5,0	15	3.5		< 2.0
Sodium mg/l	254	72	150	133	92	17	< 2.0		200 mg/l
Sulfates mg/l	50	< 1	19	44	21	7.1	< 2.0		250 mg/l

Sample Code	UWA 1	UWA 2	UWA 3	UWA 4	UWA 5	SWA 1	SWA 2
Lab Code							
Amount collected (cm3)							
Sampler	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)	CRIIRAD (B. chareyron)
Location	Borehole PC 171 in Gameleira downstream uranium prospecting area, installed by INB (2013)	Baixa da Onça near Gameleira	PEGA BEM , right bank of Riacho da Vacas : (downstream INB facilities)	Bela Vista. PC 12 (downstream INB facilities)	PC 5 Located in a stream on the left bank of Riacho da Vacas valley.	Barragem de águas claras	Dam in the Corrego do Engenho , downstream the mine and the INB uranium concentration plant
Water type	Underground water (depth 64 m) / collected at the outlet near the house / no more used for drinking	Amazonian Well , depth 6 m, used for cattle and irrigation	underground water (-60 m), collected in the tank. Used for cooking	underground water (-40 m) / collected at the pipe before the tank / used for cattle and irrigation	underground water / collected at the pipe before the tank / used for cattle and irrigation	Surface water,	Surface water, during high rainfall
GPS coordinates	13,84477	13,84348	13,83294	13,83251	13,82619	13,82948	13,8387
GPS coordinates	42,31784	42,32724	42,25351	42,25673	42,25747	42,26667	42,26842
Sampling day	11/11/2018	11/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018	12/11/2018

Metals / semi-quantitative evaluation by ICP * / results in µg/l

	UWA 1	UWA 2	UWA 3	UWA 4	UWA 5	SWA 1	SWA 2	WHO guideline for drinking water
Ag	0	0	0	0	0	0	0.4	-
Al	15	96.3	0	0	3.5	1 882	98 500	200 µg/l
As	0	0.2	0	0	0	0	5.6	10 µg/l
B	48.6	27.4	77.4	56.5	64.2	35.7	18.8	300 µg/l
Ba	118.1	118	204.6	216.2	58.5	77.6	291.3	700 µg/l
Be	0	13	0	0	0	0	4	
Cd	0	0	0	0	0	0	0	3 µg/l
Co	0.6	7.6	0	0	0	0	7.4	
Cr	0.4	0	0	0	0	0	5.4	50 µg/l
Cu	4.8	7.3	1.1	0.7	3.1	0.7	9.1	2 000 µg/l
Fe	26.9	120.1	0	0	2.5	743.4	78 600	300 µg/l
Li	24	9.6	50.2	50.5	16.8	0.3	20.6	
Mn	57.3	194.6	11.3	7.2	0.8	27.9	536.7	500 µg/l
Mo	8.8	0	5	11.2	7.4	0.6	3.5	70 µg/l
Ni	4.2	4.8	0	0.4	0	0	3.9	20 µg/l
Pb	0	5.9	0	0	0	0.4	28.6	10 µg/l
Sb	0	0	0	0	0	0	0	5 µg/l
Se	1.7	0	0.9	3	4.1	0.3	8.3	10 µg/l
Sn	0	0	0	0	0	0	5.6	-
Sr	167.3	100.4	455	366.5	279.5	107.6	28.7	
Te	0	0	0	0	0	0	0	
Ti	9.7	8.8	6	5.5	5	41.3	2 000	
Tl	0	0	0	0	0	0	0.9	
U	104.7	0.8	9.3	20	2.4	0.3	4.8	15 then 30 µg/l
V	7.0	0	1.7	4.5	0	0.3	18.6	
Zn	NM	NM	NM	NM	NM	NM	NM	3 000 µg/l

Appendix A2 / Analysis of Soil and sediments (gamma spectrometry) and results of on site monitoring at the sample collection point.

A2-1 / Methodology

Eleven samples of sediments and six samples of soil have been collected in the environment of INB uranium mine during the 3 days dedicated to the sampling of solids (November 9th, 10th, 12th).

The samples are described in Table A2-1 (next page) along with the results of the gamma radiation flux monitored at the surface of the soil.

The gamma radiation flux was measured using a **gamma scintillometer**, Model DG5, brand Novelec. This is a very sensitive device used to identify radiation anomalies and to select sampling sites. The results are expressed in **counts per second (c/s)**.

In some cases is also mentioned the result of the measurement made at 1 meter above the ground. It can be noted that the level of radiation decreases slightly with the increase of the distance to the source of the radiation (in this case, the radioactive elements present in the ground).

Samples have been packed in plastic bags with a label.

The samples have been carried by plane and received at the CRIIRAD laboratory. Each sample has been dried (105°C), crushed, sieved below 2 mm, and homogenized.

The dried material has been inserted in a calibrated plastic pot (Petri dish) for counting on an **HpGe gamma spectrometry detector** (picture A2-3).

Picture A2-3 (gamma spectrometry equipment at CRIIRAD lab).



Samples have been processed by Mrs. Sara Ortuno (laboratory technician), and Mrs. Marion Jeambrun (Dr. in geochemistry). The gamma spectra have been studied by Mr. Stephane Patrigeon (metrologist technician), Mrs. Marion Jeambrun and Mr. Bruno Chareyron.

The main results are plotted in table A2-2, next pages. They are given in **Becquerel per kilogram of dried material (Bq/kg dry)**.

No artificial radionuclide emitting gamma radiation has been detected. As an indication, the detection limits for cesium-137 (<0.8 to < 7 Bq/kg dry) are listed.

The main natural radionuclides present in the Earth's crust are uranium 238 and its descendants (such as thorium 234, radium 226, lead 210); thorium 232 and its descendants (such as lead 212) and potassium 40.

The CRIIRAD laboratory is licensed by the French Nuclear Safety Authority (ASN) for the monitoring of radioactivity in the Environment.

For solid samples (soil, sediments), the license applies to gamma emitters with an energy < 100 keV and > 100 keV; isotopes of uranium and thorium, Ra-226 and its decay products ; Ra- 228 and its decay products.

Table A2-1 / List of samples of soil or sediments collected by CRIIRAD and results of on-site gamma radiation monitoring at sampling point

Code (map)	Code (lab)	Sampling day	Location	Description	Sampling tool	GPS (S)	GPS (W)	Gamma Radiation flux (c/s), DG5	
								Contact of soil	1m above soil

Samples of soil

TS 16	201118A1	09/11/2018	Corrego do Engenho (downstream INB facilities)	Soil , Red dried clay, compact material, 30-35 cm under the surface of the track	Metal spatula	13,83214	42,26067	520 (lateral)	-
TS 19	201118A4	10/11/2018	Entrance of Horto Florestal (below waste rock dump)	Top Soil (< 1 cm) , yellow dried fine grained "clay", below a tree besides the track	Plastic shovel	13,82349	42,28822	400	350
TS 20	201118A5	10/11/2018	Entrance of track leading to Cachoeira open pit	Top Soil (< 1 cm) , yellow dried "clay and sand", middle of the track covered with solid material of yellowish color	Metal spatula	13,82635	42,29208	320	240
TS 24	201118A10	10/11/2018	Riacho da Vacas (close to a "Bacia")	Soil (< 1 cm) , radioactive rock with yellow color, besides the track, right side of the bed of the dried Riacho (collected during rainfall)	Chisel and hammer	13,82309	42,27527	1000	290
S1	201118A11	10/11/2018	Road, south of Engenho open pit	Soil , radioactive surface of the road, red sandy material, middle of the track (0-3 cm)	Chisel, hammer and plastic shovel	13,86039	42,27398	850	770
S2	201118A12	10/11/2018	Road, south of Engenho open pit	Soil , radioactive surface of the road, red sandy material, middle of the track (3-7 cm)	Chisel, hammer and plastic shovel	13,86039	42,27398	890	770

Samples of sediments

S 3	201118A17	12/11/2018	upstream Engenho open pit	Sediments (< 1 cm) , red very wet clay, area of potential accumulation of the material carried away by the water circulating on radioactive rocks located a few cms upstream	Plastic shovel	13,86004	42,27433	1200	-
S 4	201118A16	12/11/2018	"Barragem" in " Corrego do Engenho " (downstream Engenho open pit and INB factory)	Sediments (< 1 cm) , red very wet clay, area of potential accumulation of the material carried away by the water, right bank of the "lake" being filled with water after the storm	Plastic shovel and metal shovel	13,83636	42,26414	250	-
S 5	201118A3	09/11/2018	Corrego do Engenho (downstream INB facilities)	Sediments (< 1 cm) , Brown wet clay, middle of dried bed of the "Corrego", area of potential accumulation of the material carried away by the water, upstream a passage under the track	Plastic shovel	13,83196	42,26019	250	220
S 6	201118A7	10/11/2018	Corrego Gameleira (upstream Horto Florestal)	Sediments (< 1 cm) , red dried "sandy clay", besides and upstream the track, on the right bank of the bed of the "Corrego"	Plastic shovel	13,82178	42,29071	177	140
S 7	201118A6	10/11/2018	Reference : Riacho da Vacas near PC 43 (upstream confluence with "Corrego Gameleira")	Sediments (< 1 cm) , red dried "sandy clay", besides the track, on the right bank of the bed of the "Riacho"	Plastic shovel	13,81777	42,2802	200	190
S 8	201118A8	10/11/2018	Corrego on northern side of INB site	Sediments (< 1 cm) , beige dried "clay", area of potential accumulation of the material carried away by the water	Plastic shovel	13,82567	42,28167	180	160
S 9	201118A9	10/11/2018	Riacho da Vacas (downstream confluence with "Corrego Gameleira")	Sediments , beige-red dried "sandy clay", middle of the bed of the dried Riacho	Plastic shovel	13,82113	42,27913	170	140
S 10	201118A15	12/11/2018	Riacho da Vacas (downstream confluence of "Corrego Gameleira", upstream Barragem de aguas claras)	Sediments (< 1 cm) , red wet clay, extended area of potential accumulation of the material carried away by the water	Plastic shovel	13,8241	42,27198	170	150
S 11	201118A14	12/11/2018	Barragem de aguas claras (close to the pumping station near the structure of the dam)	Sediments (< 1 cm) , red dry clay on the rocks, area of potential accumulation of the material carried away by the water	Plastic shovel	13,82948	42,26667	160	-
S 12	201118A2	09/11/2018	Riacho da Vacas (upstream confluence with "Corrego do Engenho")	Sediments (< 1 cm) , Brown wet clay, middle of dried bed of the "Riacho", area of potential accumulation of the material carried away by the water	Plastic shovel	13,83134	42,26038	250	-
S 13	201118A13	12/11/2018	Riacho da Vacas (downstream confluence of "Corrego do Engenho")	Sediments (< 1 cm) , red wet clay, middle of dried bed of the "Riacho", extended area of potential accumulation of the material carried away by the water	Plastic shovel	13,83186	42,25963	180	170

Table A2-2 / Radiological characteristics of the samples of soil or sediments collected by CRIIRAD

Code (map)	Location	Description	Analysis N°	Uranium 238 decay chain						
				Th 234 * (U 238) (Bq/kg)	Radium 226 (Bq/kg)	Lead 210 *(Bq/kg)	U235 (Bq/kg)	Lead 212 (Bq/kg) (Th 232 decay chain)	Potassium 40 (Bq/kg)	Cs 137 (Bq/kg)
Samples of soil										
TS 16	Corrego do Engenho (downstream INB facilities)	Soil, Red dried clay, compact material, 30-35 cm under the surface of the track	C30345	168 ± 41	172 ± 23	172 ± 37	< 14	86 ± 12	620 ± 110	< 1,1
TS 19	Entrance of Horto Florestal (below waste rock dump)	Top Soil (< 1 cm) , yellow dried fine grained "clay", below a tree besides the track	C30355	112 ± 30	93 ± 13	85 ± 21	< 11	217 ± 25	550 ± 90	< 0,9
TS 20	Entrance of track leading to Cachoeira open pit	Top Soil (< 1 cm) , yellow dried "clay and sand", middle of the track covered with solid material of yellowish color	C30336	89 ± 30	99 ± 14	52 ± 21	< 11	271 ± 32	< 160	< 1,0
TS 24	Riacho da Vacas (close to a "Bacia")	Soil (< 1 cm), radioactive rock with yellow color, besides the track, right side of the bed of the dried Riacho (collected during rainfall)	C30317	137 ± 39	117 ± 17	112 ± 28	< 13	260 ± 31	< 70	< 1,2
S1	Road, south of Engenho open pit	Soil, radioactive surface of the road, red sandy material, middle of the track (0-3 cm)	C30367	113 ± 32	115 ± 16	96 ± 24	< 24	46 ± 7	650 ± 110	< 0,8
S2	Road, south of Engenho open pit	Soil, radioactive surface of the road, red sandy material, middle of the track (3-7 cm)	C30350	620 ± 110	1 040 ± 120	730 ± 110	< 70	192 ± 25	750 ± 130	< 1,5
Samples of sediments										
S 3	upstream Engenho open pit	Sediments (< 1 cm), red very wet clay, area of potential accumulation of the material carried away by the water circulating on radioactive rocks located a few cms upstream	C30312	290 ± 60	410 ± 50	290 ± 60	< 35	160 ± 21	800 ± 140	< 1,4
S 4	"Barragem" in "Corrego do Engenho" (downstream Engenho open pit and INB factory)	Sediments (< 1 cm), red very wet clay, area of potential accumulation of the material carried away by the water, right bank of the "lake" being filled with water after the storm	C30321	73 ± 31	93 ± 16	86 ± 31	< 16	152 ± 20	930 ± 160	< 1,4
S 5	Corrego do Engenho (downstream INB facilities)	Sediments (< 1 cm), Brown wet clay, middle of dried bed of the "Corrego", area of potential accumulation of the material carried away by the water, upstream a passage under the track	C30357	62 ± 24	56 ± 9	59 ± 22	< 12	150 ± 19	1 270 ± 180	< 1,0
S 6	Corrego Gameleira (upstream Horto Florestal)	Sediments (< 1 cm), red dried "sandy clay ", besides and upstream the track, on the right bank of the bed of the "Corrego"	C30360	99 ± 35	73 ± 13	76 ± 30	< 16	138 ± 19	694 ± 128	< 1,4
S 7	Reference : Riacho da Vacas near PC 43 (upstream confluence with "Corrego Gameleira")	Sediments (< 1 cm), red dried "sandy clay ", besides the track, on the right bank of the bed of the "Riacho"	C30332	74 ± 27	65 ± 11	63 ± 23	< 13	137 ± 17	1 050 ± 150	< 1,1
S 8	Corrego on northern side of INB site	Sediments (< 1 cm), beige dried " clay ", area of potential accumulation of the material carried away by the water	C30361	77 ± 25	52 ± 9	87 ± 24	< 11	111 ± 14	870 ± 130	< 0,9
S 9	Riacho da Vacas (downstream confluence with "Corrego Gameleira")	Sediments, beige-red dried " sandy clay ", middle of the bed of the dried Riacho	C30362	38 ± 22	40 ± 8	63 ± 21	< 12	65 ± 10	680 ± 120	< 1,0
S 10	Riacho da Vacas (downstream confluence of "Corrego Gameleira", upstream Barragem de aguas claras)	Sediments (< 1 cm), red wet clay, extended area of potential accumulation of the material carried away by the water	C30325	81 ± 32	74 ± 13	108 ± 32	< 17	162 ± 22	730 ± 140	< 7,0
S 11	Barragem de aguas claras (close to the pumping station near the structure of the dam)	Sediments (< 1 cm), red dry clay on the rocks , area of potential accumulation of the material carried away by the water	C30327	138 ± 43	144 ± 22	156 ± 41	< 25	228 ± 29	460 ± 100	< 1,5
S 12	Riacho da Vacas (upstream confluence with "Corrego do Engenho")	Sediments (< 1 cm), Brown wet clay, middle of dried bed of the "Riacho", area of potential accumulation of the material carried away by the water	C30356	83 ± 34	68 ± 13	87 ± 33	< 18	168 ± 23	990 ± 170	< 1,6
S 13	Riacho da Vacas (downstream confluence of "Corrego do Engenho")	Sediments (< 1 cm), red wet clay, middle of dried bed of the "Riacho", extended area of potential accumulation of the material carried away by the water	C30331	65 ± 30	66 ± 12	96 ± 31	< 15	135 ± 18	1 000 ± 160	< 1,5

* Possible underestimation due to self-absorption

