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Ru-106 / Mayak

Contamination with ruthenium 106

Results of soil tests carried out by the CRIIRAD laboratory in the environment of the Mayak nuclear site

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1 / Context: need to document the "Mayak" hypothesis

Following the detection of **ruthenium 106** in the air of about 30 countries from late September to mid-October 2017, the origin of the source is still debated. Among the many assumptions, that of an "incident" on the nuclear site "Mayak" was considered by CRIIRAD in October[1] and remains one of the strongest.

- This nuclear site is located in Russia, **in the sector** pointed by the modelizations of several institutes (even if it is not located in the most probable zone resulting from modelizations published on November 9th by the French IRSN and November[2] 10th by Ukrainian scientists).
- Given the extent of atmospheric contamination, the release of ruthenium 106 was necessarily **very high**. In its communication[3] of November 9th, 2017, the IRSN for its part gave an estimate of **100 to 300 TBq** or **100 000 to 300 000 billions becquerels**. It is unlikely that such a large release will come from a facility designed to produce ruthenium 106 for medical purposes.
- The Mayak site is engaged in **the reprocessing of spent fuel** and the **vitrification** of highly radioactive waste, which leads to the **regular release[4] of ruthenium 106** to the atmosphere (2.23 billion becquerels of Ru-Rh106 in 2015 according to the annual report of the Mayak site).

  In the case of accidental releases in September 2017, it seems that only isotopes of ruthenium are involved. Uncontrolled releases involving **only ruthenium** have already occurred at similar facilities, for example, in 2001, at two vitrification plants at the **spent fuel reprocessing plant at La Hague** in France. During certain stages of treatment of highly radioactive solutions resulting from the dissolution of irradiated fuels, ruthenium is indeed in **gaseous form (RuO_4)** which can easily, in the event of incidents, be massively released into the atmosphere, without other radioactive substances being released at the same time (in any case in such large quantities). RuO_4 is not stable in air and decomposes to ruthenium dioxide (RuO_2), in the form of **very fine solid particles**.

[1] http://balises.criirad.org/pdf/cp_criirad_17-10-11_ru106-air.pdf
[2] https://www.linkedin.com/pulse/detection-ruthenium-106-2017-meteorological-analysis-sources-ivan/
[3] http://www.irsn.fr/FR/Actualites_presse/Actualites/Pages/20171109_Detection-Ruthenium-106-en-france-et-en-europe-resultat-des-investigations-de-l-IRSN.aspx#.WoQGCXzkV8w
[4] In the context of "chronic" releases from the Mayak site, ruthenium 106 is not the dominant element in terms of rejected activity. According to 2015 official figures, releases of radioactive gases (argon 41, krypton 88, xenon 135) were 25,000 times higher.

- In 2017, the Mayak site obviously encountered **technical difficulties** pointed out by Nadezda Kutepova in October 2017.

Since then, other clues have supported the "Mayak" hypothesis:

- The international commission[5] of inquiry set up by Russia, validated, at its first meeting, on 31 January 2018 in Moscow, the order of magnitude[6] of the accidental release of ruthenium 106 at a value of **100 TBq, ie 100 000 billion Becquerels**.
- The technical difficulties encountered at the Mayak site were confirmed by the fact that the manufacturer told its customers, at the end of December, that it would not be able to fulfill a delivery contract for a highly radioactive **cerium 144** source. This information was revealed by the Italian press and the French newspaper Le Figaro on 2 February. However, the manufacture of this source requires the reprocessing of spent fuel relatively "fresh".
- The international commission set up by Russia concluded that the ruthenium discharge, at the end of September 2017, corresponded to "**fresh" spent fuel**. It is based on the Ru 106 / Ru 103 isotopic composition measured[7] in air in Austria, Czech Republic and Sweden.

On the other hand, the Russian authorities claim that the inspections carried out on the Mayak site found no malfunction compared to normal technological processes. In addition, the results of ruthenium 106 air contamination analysis around Mayak, published by the Russian agency Rosguidromet, are comparable to those recorded in Romania and Ukraine.

2 / Objectives of the controls carried out by CRIIRAD

Since October 2017, CRIIRAD has been trying to obtain samples of the surface layer of soils around nuclear sites in Russia that may be responsible for releases of ruthenium 106, especially around Mayak.

Regarding the Mayak site, the CRIIRAD objectives were:

- Have **independent measurements of ruthenium 106 fallout** levels in the vicinity of the facility.

  Indeed, the ruthenium 106 fallout levels around Mayak, published by the Russian agency Rosguidromet[8], did not show "strong fallout" (a few hundred Becquerels per square meter), and indicated a level of atmospheric contamination much lower than the one highlighted in Romania. CRIIRAD indicated in press releases[9] dated 21 and 22 November 2017 that these results did not correspond to "extremely high" levels, but were of the same order of magnitude as those recorded in Romania, and could not be used to "Prove" that Mayak was the source of the discharge.

- Check **current health risk levels** for the local population around Mayak due to fallout.

  Half-life of ruthenium 106 is indeed relatively long (it takes a little **more than a year** for its radioactivity to be divided by two). Performing controls is important, including several months after the fallout, even though the measurements are more and more difficult to perform and interpret as you wait.

- Beyond the question of ruthenium 106, check the level of residual soil contamination around this site which has been the subject of serious accidents[10] with massive releases to the atmosphere, particularly in **1957 and 1967**.

[5] http://en.ibrae.ac.ru/newstext/885/

[6] However, the commission did not specify why it chose the low range of the IRSN estimate.

[7] See page 7 of http://www.irsn.fr/FR/Actualites_presse/Actualites/Documents/IRSN_Report-on-IRSN-investigations-of-Ru-106-in-Europe-in-october-2017.pdf

[8] Rosguidromet Monthly Report for September 2017 http://www.criirad.org/accident-et-pollutions/X0%20byulleten_rorf_09_2017.pdf

[9] http://www.criirad.org/accident-et-pollutions/2017-11-21_cp_mise%20au%20point_1.pdf and http://www.criirad.org/accident-et-pollutions/2017-11-22_cp_mise%20au%20point_2.pdf

[10] http://www.criirad.org/installations-nucl/Mayak/CRIIRAD_Mayak_Kyshtym_Tcheliabinsk.pdf

The realization of independent controls was all the more useful as the communication of the first Russian commission of inquiry raised many questions mentioned in the CRIIRAD statement[11] of 20 December 2017.

3 / A preliminary campaign on the west of Mayak

3.1 / Measurements west of Mayak

Not having sufficient means to carry out a real cartography of the soil contamination around Mayak, the efforts were carried out within the framework of this preliminary work, on the **west of the nuclear site** and this for several reasons:

- The ruthenium-106 measurements published by Rosguidromet (air contamination and / or fallout) provided data on stations located from north-east (Metlino) to the south (Novogornyy, Argayash), so it was a priority to carry out controls on **other parts of the territory** around Mayak.
- Contamination with ruthenium 106 (regardless of the exact source), moved westward as it reached Europe. In the hypothesis that Mayak is at the origin of the discharge, it was therefore logical to control in priority the sector located in **the west**.

  It should be noted, however, that the simulations performed by CRIIRAD show that, in the event that the accidental releases occurred in Mayak, depending on the dates and times, the contaminated plumes could have moved first in other directions, especially in a northeasterly direction, before turning southwest.
- Most of the **population** near the Mayak site lives in the west, in the Forbidden City of **Oziorsk**, and in **Kyshtym**, so it was a priority to check the fallout levels in these areas.

Furthermore, with regard to the contamination in 1957 (so-called "Kyshtym" accident) and 1967 (highly radioactive dust dispersed by winds from the shores of Lake Karatchaï), the official documents indicate that the most important fallout is intervened in the northeast. Numerous studies attest to the severity of residual contamination in these areas (see, for example, measurements taken in 2008 by CRIIRAD in Golubinka[12], about 30 km northeast of Mayak). On the other hand, there are few independent measurements in the west.

3.2 / A very preliminary work

The objective of CRIIRAD was to work in successive stages. If these tests revealed a high level of ruthenium106 contamination, this would provide evidence of Mayak's liability. If not, additional sampling should be done in **additional angular areas**.

This soil analysis campaign is therefore only a first step, especially since, in the hypothesis of time-limited discharges, the trajectory of contaminated plumes at the local level is likely to be limited to a very small angular sector. The most intense fallout on the ground, which depends in addition to any precipitation (rain or snow**) may therefore affect a restricted band**.

The realization of some samples of soil is not enough to cover 360 ° around the site. It would be necessary to cover all the angular sectors and at different distances from the supposed source term.

3.3 / Difficulties encountered

It is necessary to insist here on the difficulties met to realize these preliminary surveys:

- Impossibility of approaching within 14 kilometers of Mayak due to access restrictions imposed by the Russian authorities (no-go zone).
- Difficult to find local partners to take samples.

[11] http://www.criirad.org/accident-et-pollutions/2017-12-20_cp_Ru-106_enqu%C3%AAte-russe.pdf
[12] http://www.criirad.org/installations-nucl/Mayak/CRIIRAD_Mayak_Kyshtym_Tcheliabinsk.pdf

- Checks by the authorities. A team of French journalists from TV mag “Envoyé Spécial” who went there, was also worried by the security services, during the shooting in December 2017 around Mayak.
- Difficulty of access related to the snow during the campaign of December 16, 2017.

Photo of ES2 and ES3 soil sampling by a team of French TV “Envoyé Spécial”, in December 2017

4 / Conducting soil sampling

CRIIRAD organized samplings with citizens living on site (code EK1) or teams of French journalists who went to Mayak: Mr. Laurent Valdiguié of **EBDO** magazine (code EB1, EB2, EB3 and EB4) and the team led by Mrs. Elise Ménand for the magazine **Envoyé Spécial** of the French TV “France 2” (code ES2, ES3 and ES4).

The missions were prepared during discussions with Mr. Bruno Chareyron, director of the CRIIRAD laboratory, who gave instructions on the choice of stations, the implementation of in situ radiation measurements before sampling, the taking of samples and the sample conditioning for transportation.

A total of **8 samples** were brought back to the CRIIRAD laboratory in Valence (France):

- the first one taken in **November 2017**, not far from the IZOTOP site in **Ekaterinburg** (about 110 kilometers north / northwest of the Mayak site),
- the seven others sampled in **December 2017**, between **14 and 20 km west of the Mayak** site.

For these eight stations, ground-level beta-gamma dose rate levels were comparable to natural background.

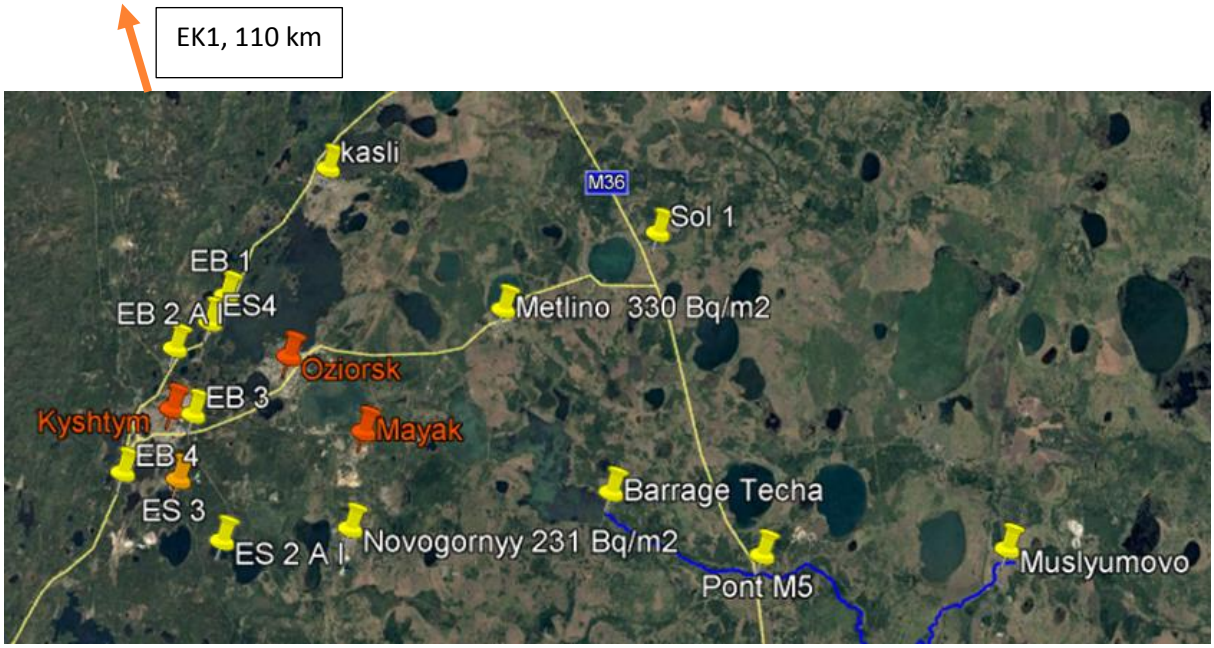
The location of samples near Mayak is shown on Map 1 below. The Mayak nuclear site, the nearby cities (Oziorsk and Kyshtym), and the villages of Metlino and Novogornyy, for which the Russian agency Rosguidromet[13] published results of ruthenium 106 (expressed in Becquerels per square meter), are also reported.

[13] http://www.criirad.org/accident-et-pollutions/X0%20byulleten_rorf_09_2017.pdf

On this map also appear, for the record:

- the "Sol 1" sample collected by CRIIRAD in **2008** in **Goloubinka**, about 30 kilometers north east of Mayak. The analysis confirmed the very high residual contamination by **cesium 137** (**255 000 Bq/m²**), most likely due to the fallout from the **1957 accident**.
- the course of the **Techa River** to the village of **Muslyumovo**. The studies[14] carried out by CRIIRAD in **2008** and **2010** confirmed the contamination of the waters, the high contamination of the banks of the river and the exposure of the population of Muslyumovo to unacceptable levels of risk.

Map 1 / Location of soil sampling sites (application: GoogleEarth)



5 / Results of soil analyzes

Soil samples were analyzed by **gamma spectrometry**[15]. This method makes it possible to detect ruthenium 106 (from its decay product **rhodium 106**) and other artificial radionuclides (cesium 134, cesium 137, iodine 129, americium 241, etc.).

The CRIIRAD laboratory is approved by the Nuclear Safety Authority for the measurement of gamma emitting radionuclides in the ground matrix.

On the other hand, gamma spectrometry does not allow the detection of pure beta emitting radionuclides (tritium, carbon 14, strontium 90, plutonium 241) or pure alpha emitting ones (plutonium 238, 239 and 240), which are nevertheless present in radioactive releases from the Mayak nuclear site.

The main results are reproduced in Table 1 on the following page.

[14] http://www.criirad.org/installations-nucl/Mayak/somdemayak.html

[15] The samples were processed and analyzed by Christian Courbon, a specialized technician, Stéphane Patrigeon, a metrology technician, Marion Jeambrun, a doctor in geochemistry, and Bruno Chareyron, an engineer in nuclear physics.

The analysis results for natural radionuclides are not mentioned here. The activities of potassium 40 (<400 Bq/kg), radionuclides of the thorium 232 (<40 Bq/kg) and uranium 238 (<40 Bq/kg) decay chains are conventional, with the exception of lead 210 (decay product of radon 222 from the uranium 238 decay chain) whose activity reached 820 Bq/kg in one sample.

Table 1 / Artificial gamma-emitting radionuclides in the surface layer of soils

					Activity of artificial radionuclides (gamma emitters) in Bq/kg				
Code	**Location**	**Sampling date**	**Sampled by**	**State (0)**	**Cesium 137**	**Ruthenium 106** (from Rhodium 106)	**Americium 241**	**Iodine 129**	**Ruthenium 106 fallout (Bq/m2)** (1)
EK 1	South-east of EKATERINBURG / 200 m from IZOTOP / about 115 km North of Mayak	18/11/2017	Citizen	dry	131 ± 17	< 9	< 0.9	< 1.0	< 68
EB 1	16 km West / North-West from Mayak, side of a road , north of Kyshtym, near a lake	07/12/2017	l'EBDO	dry	26 ± 5	< 12	< 1.3	< 1.3	< 38
EB 2	17 km West from Mayak, North of Kyshtym, under electric power line	07/12/2017	l'EBDO	dry	226 ± 25	< 6	4.5 ± 1.4	1.7 ± 1.1 (2)	< 83
EB 3	14 km West from Mayak,between Kyshtym and Oziorsk (close to a forest)	07/12/2017	l'EBDO	wet	56 ± 8	< 7	< 0.7	< 0.7	< 185
EB 4	20 km West /South-West Mayak	07/12/2017	l'EBDO	dry	22 ± 4	< 8	< 0.9	2.5 ± 1.4 (2)	< 200
ES 2	14 km South-West Mayak	17/12/2017	Envoyé Spécial	Wet	189 ± 20	< 2.6	9.5 ± 1.5	2.9 ± 0.8	< 115
ES 3	15,5 km West / South-West Mayak	16/12/2017	Envoyé Spécial	dry	4.7 ± 0.9	13.2 ± 4.4	< 0.25	< 0.24	580 to 1 200
ES 4	16 km West / North-West Mayak	17/12/2017	Envoyé Spécial	dry	53 ± 7	< 6	< 0.7	< 0.7	< 309

Legend of the table

Note (0): the specific activities are given in becquerel per kilogram of wet material (Bq/kg w) or material after drying in an oven (Bq/kg d), depending on whether the samples were analyzed "raw" or after desiccation (dry).

Note (1): the level of surface fallout is deduced from the mass activity recorded in the topsoil (4 to 10 cm deep depending on the site). Contrary to what had been agreed prior to the completion of the field missions, the sampled area has, in some cases and given the field constraints, not been measured but estimated. The results are therefore given with a greater margin of uncertainty. The values are systematically corrected for the decay of ruthenium 106 between the time of the analysis and a "plausible" fallout date assumed on September 26, 2017, taking into account the data published by Rosguidromet.

Note (2): the specific activity is given with a relatively high margin of uncertainty. More soil would be needed to refine the measurement.

5.1 / Detection of ruthenium 106

Ruthenium 106 (detected from its gamma emitting decay product rhodium 106) has measurable activity in a single sample (ES 3) with an activity of **13.2 ± 4.4 Bq/kg dry**, which corresponds to a deposition of **580 to 1,200 Bq/m²**.

This value constitutes a default assessment of the initial deposit to the extent that it can not be ruled out that part of the ruthenium 106 has penetrated beyond the depth[16] of withdrawal or has been "exported from the ground" between the time of deposit and the time of sampling.

Moreover, even if the samples were not taken in the forest, they were sometimes on the edge of wooded areas with the possibility that some of the atmospheric contamination was intercepted by the foliage depending on the angle.

In the other samples, ruthenium 106 is not detected. This does not mean that it is not present in the sample, but that its activity is less than the detection capacity of the method used. The results are then expressed in the form *"<, lower*" than the **limit of detection**. This detection limit varies[17] from <2.6 Bq/kg fresh to <12 Bq/kg dry, which, expressed in becquerels per square meter, corresponds to values **<38 Bq/m² to <309 Bq/m²**.

A level of ruthenium 106 fallout from 580 to 1,200 Bq/m² is significantly higher than the values published by the Russian agency Rosguidromet[18] which indicated, for the stations near the Mayak site, a maximum value of **330 Bq/m²** at Metlino, about 15 km northeast of Mayak (deposit 26-27 September 2017).

Fallout levels of several hundred Bq/m² are clearly abnormal, but they do not support the conclusion that the September 2017 release is from Mayak, neither that it is not from Mayak.

These levels are broadly consistent with the available results for ambient air contamination. Indeed, Rosguidromet published, for the period from September 26 to October 1, values between 18 and 46 mBq/m³ for the stations of Argayash (23 km south-east of Mayak) and Novogornyy (8-10 km South).

Comparison with 2001 releases at " La Hague"

A report[19] of the Group of Pluralist Expertise (GEP) "Nord Cotentin" published in 2002 focused on the analysis of incidents of uncontrolled releases of ruthenium 106 that occurred in 2001 at two vitrification plants at the La Hague reprocessing plant (France).

According to the GEP, for the May 2001 incident, samples taken downwind from factory chimneys (angle of about 50 degrees) and distances of 500 to 7,000 meters, indicated maximum fallout from RuRh-106 of **2,000 Bq/m² at 800 meters** from the chimney, which made it possible to estimate the discharge around **50 billion becquerels** (from the deposit on the ground).

An estimate based on the contamination of the air detected at 200 km downwind (14.8 µBq/m³) gave a value of 5 billion becquerels, a value 10 times lower, but consistent with the measurement carried out on the aerosols leaving the vitrification workshop (4.5 billion Bq).

In La Hague, a discharge of **several billion becquerels** led to a fallout of **2,000 Bq/m² 800 meters** from the chimney.

[16] However, this is unlikely since the samples were taken less than 3 months after the deposits and the ruthenium element is a priori not very mobile in the ground, moreover frozen at this time of the year.

[17] The variability of the detection limits is related to the specific conditions of this study (low quantity of material, need to count some fresh samples without drying and others after drying, need to count some samples faster than others given the specific constraints).

[18] http://www.criirad.org/accident-et-pollutions/X0%20byulleten_rorf_09_2017.pdf

[19] Report of the Groupe de Travail « Ruthénium », final version of October 3, 2002.

The example of “La Hague” shows:

- That, if there was indeed in Mayak at the end of September 2017, a release of 100 000 billion becquerels of Ru 106 and that it was carried out in weather conditions close to that of May 2001 in La Hague, one can expect very large local fallout of **several hundred thousand or even several million Bq/m²**. Such levels of impact present a real health challenge, **requiring the immediate implementation of protective measures**.
- In the case of a short-term discharge, the most significant fallout may concern only a **very limited angular sector**. To find the maximum fallout area, you need to know the dates and times of the releases and the precise weather conditions at that time (wind speed and direction), or make an exhaustive mapping of the contamination of the environment for all the angular sectors.
- It is **very difficult to model the local fallout** in the case of ruthenium gas release. In the case of La Hague, the data review allowed according to the GEP "*to highlight the role of ultra-fine aerosols created during the condensation or reduction of gaseous RuO_4. These ultra-fine particles have deposition rates very important (an order of magnitude greater than that of natural aerosols) and a very short lifetime by coagulation with natural aerosols in the atmosphere. These characteristics explain the significant deposits measured close to the discharge point (ultra fine aerosols*) ".

  In its information note of 9 November 2017, IRSN estimated[20] that, in the environment of the site at the origin of the September 2017 discharges, the radioactive deposits on the ground could reach **60 000 to 100 000 Bq/m² up to 40 km** and **2 million Bq/m² less than 2 km** from the site. However, IRSN did not give details of its working hypotheses (in particular local weather conditions: wind direction and speed, precipitation, physico-chemical form of ruthenium, duration of discharges, etc.) and related uncertainties. However, these parameters can lead to very different fallout configurations.

5.2 / Detection of other artificial radionuclides

The measurements made by CRIIRAD on soils collected in December 2017 west of Mayak show contamination by other artificial radionuclides.

Cesium 137

Cesium 137 is detected **in all soil samples**, with values ranging from **4.7 ± 0.9 Bq/kg dry** to **226 ± 25 Bq/kg dry**. Cesium 137 is a beta-gamma emitter and a fission product with a half-life[21] of **30 years**.

This contamination can come from the fallout from particularly intense atmospheric nuclear tests in the 1950s and 1960s, from the fallout from Chernobyl in 1986, and of course from Mayak, particularly from accidents in 1957 and 1967.

Even though the 1957 and 1967 fallout has been much more intense north-east of Mayak, it is likely that areas to the west have not been totally spared. According to the official maps, the city of Kyshtym is one of the areas that received, during the 1967 accident, a fallout below 11,100 Bq/m² for cesium 137, which corresponds to a residual surface activity of less than 3,400 Bq/m² after 50 years, due to the decay of this isotope.

The analysis of the surface layer of soils (4 to 10 cm depending on the station) that the CRIIRAD performed, gives a residual impact compatible with these data. It should be noted that, in order to evaluate old levels

[20] http://www.irsn.fr/FR/Actualites_presse/Actualites/Documents/IRSN_NI_Ruthenium-106-en-Europe_20171109.pdf Extract: "*The contamination related to the deposit directly on the mushroom can not exceed the maximum admissible level defined by Euratom Regulation 2016/52 of 1,250 Bq/kg unless if it is collected in a zone where the surface contamination is between 60,000 and 100,000 Bq/m². According to IRSN's estimates for this event, only fungi collected in a 40 km zone around the site that has rejected ruthenium are likely to have a contamination higher than the European standards*".

[21] The half-life is the time required for the radioactivity to be divided by 2.

of fallout, the CRIIRAD laboratory is carrying out deeper[22] soil samples (40 to 50 cm) in order to quantify cesium 137, which has had time to migrate [23]deeply.

Iodine 129 and americium 241

The analyzes carried out by CRIIRAD revealed the presence of **iodine 129** in 3 soil samples (of the order of a Becquerel per kilogram) and **americium 241** in 2 samples (of the order of a few becquerels per kilogram).

These are artificial radionuclides with a long or very long half-life (**433 years** for americium 241 and **15.7 million years** for iodine 129).

Americium 241 is a very radiotoxic radionuclide and its presence is a sign of that of plutonium. Iodine 129, americium 241 and **plutonium** isotopes are released from reprocessing plants and may come from Mayak's activities.

It is not possible, as part of this preliminary work, to distinguish the part attributable to current releases (in 2015, Mayak declares[24] to have released into the atmosphere 421 million becquerels of plutonium 239 or equivalent radionuclides) from the remainder of the old disasters. To do this, it would be necessary to carry out coring to reconstruct the contamination profiles and carry out further measurements (quantification of plutonium isotopes and determination of isotopic ratios).

To decide on the health impact of these contaminations for the local population, it is essential:

1 / to carry out independent verifications in the field and,

2 / get more details from Mayak on:

- its current radioactive releases (it is surprising not to find iodine 129, or tritium and carbon 14, in the list of elements released into the atmosphere, whereas reprocessing plants usually reject them in large numbers),
- levels of environmental contamination in the sector (air, water, soil, fauna, flora, food chain).

[22] http://www.criirad.org/actualites/tchernobylfrancbelarus/tchernobylmisajourjuil05/Rapport_N_17-34%20_Sols_Rh%C3%B4ne-Alpes.pdf

[23] In Table 1, for cesium 137, only the specific activity is given, without evaluation of the surface activity. An assessment based on the first 4 to 10 cm of soil would strongly underestimate the remnant surface activity. Indeed, since this radionuclide has a relatively long half-life and a large share of the fallout may have occurred decades ago, a significant fraction of the contamination has probably migrated into deeper soil layers. Not to mention the loss over time linked to other factors, as shown by the successive campaigns carried out by CRIIRAD on soils in France.

[24] See page 40 in http://www.rosatom.ru/upload/iblock/9df/9df0a3166368ab5271dfbefa056fd11e.pdf

6 / Conclusion

The laboratory of the CRIIRAD (Commission for Independent Research and Information on RADioactivity), based in Valence (France) carried out soil analyzes taken in **December 2017** between **14 and 20 km west of Mayak**.

These analyzes confirmed a significant **ruthenium 106 contamination**, which can reach **580 to 1,200 Bq/m²**, which is appreciably higher, but compatible with those found in September 2017 by the Russian agency Rosguidromet (a few hundred Bq/m^2).

These results have not led to a conclusion on the question of the origin of ruthenium 106. In fact, they do not correspond to the very strong theoretical fallout expected locally in the event of an estimated release of 100 000 billion of Becquerels.

It should be noted, however, that if the releases lasted only a short time, the locally most contaminated areas may be in a small angular sector that has not been sampled.

In addition, the feedback from uncontrolled releases of ruthenium 106 that occurred in 2001 at the La Hague site (France) shows that, **very close to the installation**, there can be much more significant fallout than estimates given by the usual models of dust deposition.

More than 4 months after the releases, the Russian authorities have **still not published detailed mapping** of the **level of soil contamination** and bioindicators around Mayak.

It is therefore essential to conduct an independent environmental analysis program around Mayak, with a concentric circle sampling plan of increasing radius, and taking into account the weather conditions in the anticipated period of discharges.

It is imperative to add sampling stations, especially in the North sector, but also closer to Mayak. Since a large part of the study area is closed to access by the Russian authorities, part of these samples can only be taken if the **authorities lift these prohibitions**.

The carrying out of independent and in-depth controls is all the more justified since CRIIRAD has identified contamination of very long-lived radionuclides in the west of Mayak, **americium 241 (433 years)** and **iodine 129 (15.7 million years).** The presence of americium 241 in the surface layer of soils indicates that of **plutonium**.

CRIIRAD calls on the Russian authorities to make public the **exhaustive list and quantity of radioactive substances released to the atmosphere** by the Mayak site as well as the complete results of analyzes carried out on **soil, air, water, fauna, flora and the food chain**.

It also calls for the authorization of **independent** soil radioactivity and terrestrial bioindicator controls **closer to the nuclear site**.