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Analysis of legal responsibility for natural radioactive anomaly in the wild semi-arid region of Pernambuco

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Abstract**—***High concentrations of uranium-238 (^{238}U) and thorium-232 (^{232}Th) were found in rocks of the natural radioactive anomaly existing in the cities of Pedra and Venturosa located in the State of Pernambuco. The studies were carried out in a technical partnership between the former company NUCLEBRÁS and CPRM, in 1975. After exhaustive prospecting studies, the anomaly was considered economically unfeasible for mining. Although the anomaly was considered economically unviable, the inhabitants of the municipalities of Pedra and Venturosa are subject to high levels of natural radiation. In Brazil, the exploration of radioactive ores is the responsibility of the Union, and the National Nuclear Energy Commission (CNEN) is responsible for the management of such resources, with the Nuclear Industries of Brazil (INB) being responsible for mining activities. In CNEN regulations there are no radiological protection measures that must be adopted in the case of natural radioactive anomalies considered economically unfeasible. Thus, and within this context, the present study aimed to research, within the scope of Brazilian legislation, the legal responsibility for the natural radioactive anomaly of the cities of Pedra and Venturosa. For that, a bibliographic review search was used in the specialized literature. The results obtained showed that, legally, CNEN is responsible for the natural radioactive anomaly located between the cities of Pedra and Venturosa, and, therefore, it must adopt mitigation measures of radiological protection in the area where the anomaly is located.*

Keywords**—Law, Nuclear Law, Radioactive ores, Radioecology**

I. INTRODUCTION

In the state of Pernambuco there is one of the largest radioactive anomalies in Brazil, which is located between the cities of Pedra and Venturosa, in the region of Agreste Semiárido. The mineral prospecting research carried out by the former company NUCLEBRAS, in 1975, in partnership with CPRM, in the municipalities of Pedra and Venturosa, initially showed that the extraction of uranium ores was economically viable in the area that includes these municipalities, however, more detailed studies concluded that the depth of the deposit was shallow, which made its exploration unfeasible [1]. However, from the point of view of radioecological protection, this is very important, since mineral exploration works spread natural radioactive materials on two milk producing farms in the municipalities of Pedra and Venturosa. These materials are still in their respective locations until today. It is stated in Brazilian laws that the issue of the nuclear fuel cycle starts from the mining of uranium ores to the production of nuclear energy in the plants, with the Union having a monopoly on nuclear activities in Brazil. The exploration of radioactive ores in Brazil is also linked to mining law and the existing rules in the Mines Code must be observed [2]. Thus, there is an

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expectation that the Union will also be responsible for radioactive anomalies considered economically unviable, as is the case of that existing in the municipalities of Pedra and Venturosa.

Brazil is one of the most cited countries when it comes to the environment. The country has sought to balance its need for socio-economic growth with environmental requirements, being aware that environmental issues are of global interest, demanding, even from other countries, a transparent and competent attitude towards the environment. Article 225 of the Federal Constitution of Brazil establishes that "everyone has the right to an ecologically balanced environment, a good for the common use of the people and essential to a healthy quality of life, imposing on the Public Power and the community the duty to defend it and preserve it for the present and for future generations"[3]. Article 225 of the Federal Constitution of Brazil also covers the Brazilian nuclear issue, from the mineral exploration of uranium to the decommissioning of nuclear plants. All nuclear activities must be carried out in such a way that there is unrestricted preservation of the environment in all biotic and abiotic aspects, including preserving the human being from undue exposure to radiation. Exposure to radiation from natural radioactive anomalies considered economically unviable is also covered by the constitutional text.

Natural radioactive anomalies considered economically unviable need to be assessed within the context of radiological protection, considering all radioecological aspects. In natural anomalies, radioactive elements are associated with materials such as rocks and soils that are known in the specialized literature as NORM (Naturally-Occurring Radioactive Materials). However, in these materials, the concentrations of natural radionuclides vary widely, depending on their origin. The high concentrations of natural radioactive elements in materials expose humans to the risks of the effects of ionizing radiation. The municipalities of Pedra and Venturosa located in the AgresteSemiárido region of Pernambuco, currently have the largest natural radioactive occurrence in the state. Studies have shown that the inhabitants of the municipalities of Pedra and Venturosa are subject to high levels of natural radiation, significantly increasing the risk of cancer in the local population [4].

When a given population is exposed to radiation from natural anomalies considered economically unviable, strict laws are needed to deal with the issue of environmental radiological protection, especially when it comes to mitigating the possible effects caused on humans. The National Nuclear Energy Commission (CNEN) does not have in its normative measures measures that must be adopted for radiological protection in natural radioactive anomalies considered economically unfeasible. As a regulatory and supervisory body, CNEN should include in its normative provisions, monitoring studies in areas with natural radioactive anomalies, but which do not have economic interests. In the 1988 Constitution it is written that the monopoly, research and mining of nuclear ores and derivatives is a competence of the Union. INB (Nuclear Industries of Brazil), a company controlled by CNEN, is responsible for the exploitation of uranium, from mining and primary processing to the production and assembly of the fuel elements that power the nuclear reactors [2].

There should be normative provisions at CNEN that legislate about the possibility of creating remediation processes in areas with radioactive anomalies considered not economically viable. Depending on the situation of each anomaly, radioactive ores could be removed from the site and taken to a uranium processing unit, or more viable remediation processes could be established for each location. In 2015, 195 countries agreed that they can change the world for the better. This is being done by bringing together their respective governments, companies, media, higher education institutions and local NGOs to improve the lives of people in each country, by the year 2030. For this purpose, the so-called Sustainable Development Goals (SDGs) were created. which includes the protection of the environment and the protection of people. So, adopting mitigation measures in areas with natural radioactive anomalies considered economically unfeasible, means protecting the population's health against possible harmful exposures of ionizing radiation.

Therefore, and within this context, the present study aimed to investigate the Brazilian law, the legal responsibility of Organs competent bodies in relation to the mitigating measures that must be adopted in the area where there is a natural radioactive anomalous occurrence in the municipalities of Pedra and Venturosa, aiming to mitigate the effects caused by ionizing radiation in the local population.

II. METHODS

In the present work, the methodology of bibliographic survey in the specialized literature was used, with an emphasis on more general nuclear questions about radioecological research and nuclear legislation, focusing on natural radioactive anomalies considered economically unfeasible, specifying the case of natural radioactive anomaly existing in the municipalities from Pedra and

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Venturosa, located in the wild semi-arid region of the state.

III. RESULTS AND DISCUSSION

3.1 Main radioactive anomalies in the world

In the last few years, concern about the exposure of man to natural radioactivity has been growing. The natural radioactive series of ^{238}U and ^{232}Th and their decay products, as well as ^{40}K, contribute significantly to the increase in human exposure to natural radiation [5]. Materials that contain in their composition, these radioactive elements and their decay products, are named in the scientific literature of NORM. The term NORM is an acronym for naturally occurring radioactive material (Naturally Occurring Radioactive Material), which includes all natural radioactive elements found in the environment [6]. In the magazine Applied Radiation and Isotopes, in volume 49, number 3 of March 1998, entitled, Naturally Occurring Radioactive Natural in the Environment, topics related exclusively to the problem of natural radionuclides and their consequences for man and the environment were addressed. Several symposia and congresses have been held around the world with the purpose of discussing topics related to natural radionuclides. Of these, the symposium held in Amsterdam, the Netherlands, from September 8-10, 1997, stands out. This Symposium was entitled, International Symposium on Radiological Problems with Natural Radioactivity in the Non-Nuclear Industry. It was divided into six sessions, with different topics that mainly addressed topics related to regulation and legislation regarding natural radionuclides [7].

Countless countries, including Brazil, carry out studies on the concentrations of natural radioactive elements in biotic and abiotic systems, aiming to protect human beings from the harmful effects caused by radiation. Concern about the risks of increasing exposure to natural radioactivity is also present in Brazil. As determined by the National Nuclear Energy Commission (CNEN), the Institute of Radioprotection and Dosimetry (IRD) has been coordinating, since 1996, a very broad research program to assess the extent of the problem in the country (especially in the mineral sector), to define priority lines of research and propose action strategies based on the results obtained. In a broader sense, these results guarantee protection for workers in the sectors involved and the population in general. To broaden the discussion on the topic of natural radioactivity in the country, the IRD held in Buzios, Rio de Janeiro, in 2007, the Symposium entitled: The Natural Radiation Environment 8th International Symposium (NRE VIII) [8].

Locations with high amounts of natural radionuclides are called by the scientific literature of anomalous regions. Dosimetric, radiobiological and epidemiological studies have been carried out in residents of areas considered to be typically anomalous in Brazil, India, China, Iran, Austria, Sudan, United States, Canada and other countries [5].

In Brazil, the main anomalous areas are those associated with the natural occurrence of uranium and thorium. In the states of Espírito Santo, Rio de Janeiro and Minas Gerais, the main thorium anomalies are associated with monazitic sands [5]. The city of Poços de Caldas, in Minas Gerais, is located under an alkaline intrusion with high levels of uranium and thorium [9]. In Caetité, Bahia, Itataia in Ceará and Espinhara in Paraíba, uranium anomalies are associated with high concentrations of U_3O_8[8]. Brazil has the seventh largest uranium geological reserve in the world, with approximately 309,000 tons of U_3O_8[8]. Research on the concentrations of U_3O_8 in the amphibolytic calcio-silatic rocks existing in the cities of Pedra and Venturosa, located in the so-called “Milk Basin” of the state of Pernambuco, revealed a maximum value of 22,000 $mg.kg^{-1}$[1]. In addition to the element uranium, these studies also showed that the average concentration of ThO_2 in the rocks of these municipalities was approximately 100 $mg.kg^{-1}$[10].

Studies have shown that ^{238}U, ^{232}Th, its decay products and ^{40}K are found in the soil, due to the weathering of the rock that contains these radionuclides [11] [12]. Once in the soil, these elements are easily absorbed by plants, reaching animals and then man [12]. When ingested or inhaled by humans, natural radionuclides are incorporated into a specific organ, which can generate various malignancies, including the most fearful of all, cancer. Due to the fact that the municipalities of Pedra and Venturosa are located in the region with the highest dairy cattle production in the state of Pernambuco, the consumption of milk and dairy products is an important way of incorporating natural radionuclides into the local population. Studies carried out on dairy farms in the municipalities of Pedra and Venturosa, showed that the consumption of milk and dairy products is the primary route for the intake of natural radionuclides by the local population [4].

3.2. The radioactive anomaly in the AgresteSemiárido region of Pernambuco

In 1975, the former company NUCLEBRAS (Brazilian Nuclear Companies) and MRRC (Mineral Research and Resources Company) carried out geological

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studies in the Northeast region of Brazil, and identified 263 natural radioactive anomalies, however, only one of them presented high concentrations uranium and thorium [13]. In the years 1977 and 1978, the former NUCLEBRAS carried out a new geological survey and profiling project that became known as the Venturosa Project - Assessment of areas [13]. These studies identified high levels of uranium and thorium in rocks existing in an area of dairy farms in the municipalities of Pedra and Venturosa, near the Ipanema River. Maximum U_3O_8 values of 22,000 ppm and 100 ppm of ThO_2 were found in the rocks of the region [10].

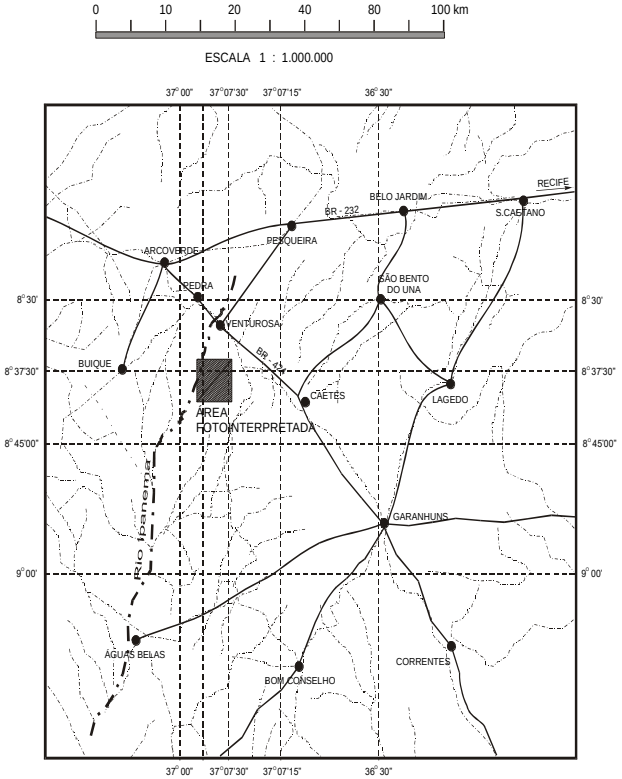

Fig 1. Map of the area delimited for study (photointerpreted area).
Source: Silva et al. (2004).

In 1986, the Venturosa Project was reevaluated, and georadiological research was resumed with the purpose of evaluating the economic viability of the primary exploration of uranium mineralizations[14]. In 1988, photointerpretation studies were carried out on an area of 100 km^2 in the municipality of Venturosa (Figure 1), and also in its surroundings, where an area of approximately 20 km^2 was delimited, which houses the main primary uranium mineralizations of the municipality [13]. In this area are located the main farms producing milk and dairy products in the municipalities of Pedra and Venturosa, being the object of study of this research.

Figures 2 and 3 show outcrops of rocks containing uranium and thorium ores in dairy farms in the municipalities of Pedra and Venturosa, respectively. Figure 4 shows cattle ranching and planting forage palm on a farm in Venturosa.

Fig 2. Rocks containing uranium ores in the municipality of Pedra.
Source: Silva and Costa Júnior (2019).

Fig 3. Rocks containing uranium ores in the municipality of Venturosa.
Source: Silva and Costa Júnior (2019).

Fig 4. Cattle breeding and planting of forage palm on a farm in Venturosa.
Source: Silva and Costa Júnior (2019).

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3.3. Radioecological studies carried out in Pedra e Venturosa

Researchers from the Nuclear Energy Department (DEN) of the Federal University of Pernambuco (UFPE) carried out several studies on the natural radioactive anomaly located between the cities of Pedra and Venturosa in Pernambuco. They analyzed biotic and abiotic samples, and many scientific data on the area were published in different national and international journals. From the radioecological point of view and the environmental radiological protection, the natural radionuclides ^{226}Ra, ^{228}Ra and ^{210}Pb were considered the most important.

3.3.1. Natural radionuclides in rocks and soils

The first studies on the presence of natural radionuclides in rocks and soils from the radioactive anomaly of Pedra e Venturosa were carried out by Santos Júnior [15]. According to this author, the amphibolytic calcium-silicate rocks, a type of rock existing in the region, showed concentrations of uranium-238 (^{238}U) and radio-226 (^{226}Ra) ranging from 16,567 to 95,980 Bq.kg^{-1} and 14,018 to 83,567 Bq.kg^{-1}, respectively. In the case of soil, the concentrations of uranium-238 (^{238}U) and radio-226 (^{226}Ra) ranged from 22 to 268 Bq.kg^{-1} and 14 to 367 Bq.kg^{-1}. In another study, Santos Júnior et al. [16] determined concentrations of radium-228 (^{228}Ra) in soil samples, ranging from 73 to 429 Bq.kg $^{-1}$.

Soils contaminated with monazitic sand processing residues in the state of São Paulo, presented concentrations of ^{228}Ra and ^{226}Ra ranging from 153 to 33,000 and from 50 to 6,500 Bq.kg^{-1}, respectively [17]. In these soils mitigation measures were adopted for remediation. It is observed that some values of the concentrations of ^{228}Ra and ^{226}Ra in soil samples from the radioactive anomaly of the cities of Pedra and Venturosa are within the range of values determined by Lauria and Rochedo[17]. This indicates that a more detailed study would be necessary to verify the possibility of mitigation measures for remediation in the soils existing in the locality of the radioactive anomaly of the Pernambuco and Pedra de Venturosa cities.

In the studies carried out by Silva et al. [18], high concentrations of radioactive lead (^{210}Pb) were determined in samples of rocks and soils from the radioactive anomaly of Pedra e Venturosa, whose values ranged from 3.2 to 201 kBq.kg^{-1} and 195 to 86,400 Bq.kg^{-1}, respectively. The big problem with the ^{210}Pb element is that, in addition to being radioactive, it is also quite toxic to animals, plants and humans.

3.3.2. Natural radionuclides in forage plants

The mechanism of incorporation of natural radionuclides in forage plants varies considerably. In natural conditions, ^{226}Ra is transported directly from the soil to the roots [9]. On the other hand, the presence of ^{210}Pb in forage plants is mainly due to the natural fallout of ^{222}Rn [19][9]. Forage plants efficiently absorb natural radionuclides. Studies carried out on dairy farms in the cities of Pedra and Venturosa, show that forage palm (*Opuntia ficus-indica*), bufell grass (*Cenchrus ciliares*) and elephant grass (*Pennisetum purpureum*) consumed by dairy cows, absorbed high amounts of ^{226}Ra (SILVA et al., 2004), ^{210}Pb [18] and ^{228}Ra [20].

3.3.3. Natural radionuclides in milk and dairy products

Natural radionuclides are efficiently transferred from forage plants to cow's milk [21][22]. Scientific studies that address the presence of natural radionuclides in fresh cow's milk samples coming directly from producing farms are quite scarce in the specialized literature. In the samples of milk and fresh products collected in the farms producing the cities of Pedra and Venturosa, concentrations of ^{226}Ra [23] [24], ^{210}Pb [25] and 228Ra [26].

3.3.4. Natural radionuclides in the human body

The transfer of ^{226}Ra, ^{228}Ra and ^{210}Pb in the soil-forage-milk-plant system is one of the main internal exposure routes in man, due to the consumption of milk and dairy products [27].

^{226}Ra and its decay products are responsible for the largest fraction of the internal dose received by man, due to natural sources. When ingested or inhaled, their decay products offer a high potential risk to human health and may induce the appearance of cancer [28].

^{228}Ra is an element of great radioecological interest, as, like ^{226}Ra, it is present in water and food eaten by humans. Radium is an element chemically similar to calcium and accumulates mainly in the human skeleton. Ingestion of radium can induce the appearance of sarcoma in the bones [29].

A high incidence of bone cancer was found in women who painted watch faces with luminescent paint composed of ^{226}Ra and ^{228}Ra, in the period from 1913 to 1926. These people tuned the brush with their tongue, thus ingesting the radio isotopes [30]. Postmortem studies, carried out on the bones of these women, showed several types of sarcomas in their skeletal structures [29].

Food intake is recognized as the most important route of contamination with ^{210}Pb in man [31]. Once ingested, this radionuclide is deposited in the liver and

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bones, and can induce various types of health damage. ^{210}Pb is preferred to deposit in the trabecular and cortical bones [31]. Approximately 70% of the ^{210}Pb present in the human body is deposited in the bones, the rest being distributed in the soft tissues [31]. The accumulation of ^{210}Pb in the bone occurs through ion exchange between Pb^{+2} and Ca^{+2}, hence the metabolic similarity of lead with calcium in the body, although the metabolic mechanisms are not necessarily identical [32]. Environmental radioprotection studies carried out by Silva et al. [4] and Silva and Costa Júnior [20] showed that the systematic intake of milk and derivatives containing ^{226}Ra and ^{228}Ra, by the population of the cities of Pedra and Venturosa, considerably increases the concentrations of these elements in the bones, resulting in an increased probability the occurrence of sarcoma and osteosarcoma.

3.4. Analysis of nuclear damage

After different radiogeological studies carried out by the former company NUCLEBRAS on the natural radioactive anomaly existing in the cities of Pedra and Venturosa, it was found that, from the point of view of uranium exploration, it was economically unfeasible. However, no study has been carried out to verify the presence of radioactive elements in the food chain of the local population. Thus, no study has been carried out to verify the population's exposure levels to natural radiation. The arguments presented in items 3.3.1 to 3.3.4 lead us to a discussion about the possibility of expanding the legal questions about the nuclear damage caused by natural radioactive elements.

In Brazil, nuclear damage is associated only with nuclear activities, since all activities that use nuclear energy are classified as dangerous and have imminent risks of accidents. Thus, the concept of nuclear damage does not include damage caused by NORM (Naturally-Occurring Radioactive Materials) - Naturally Occurring Radioactive Materials to humans, which automatically excludes all natural radioactive occurrences. However, item d) of paragraph XXIII of article 21 of the 1988 Constitution [3] says that: “civil liability for nuclear damage does not depend on the existence of guilt”. This truly opens up the range of discussions on third party liability for nuclear damage. Since the population of Pernambuco's cities of Pedra and Venturosa is exposed to high levels of NORM, who is responsible, in this case, for the legal responsibility for nuclear damage?

Law No. 6,453, of October 17, 1977, provides for civil liability for nuclear damage and criminal liability for acts related to nuclear activities [33]. This law defines nuclear damage:

Article 1 - For the purposes of this Law, it is considered:

(...)

VII - “nuclear damage” means the personal or material damage produced as a direct or indirect result of the radioactive properties, their combination with the toxic properties or with other characteristics of the nuclear materials, which are in or derived from a nuclear installation. sent;

Law No. 6,453 / 77 is also specific on civil liability for nuclear damage:

Art. 4 - Civil liability for the repair of nuclear damage caused by a nuclear accident will be exclusive to the operator of the nuclear installation, under the terms of this Law.

Analyzing the entire Law No. 6,453 / 77, it was found that there was no civil liability for damages caused by exposure to radiation from naturally occurring radioactive anomalies, and which mitigating measures should be adopted for these cases.

Law No. 4118/62 [34] gave CNEN the responsibility for exploring the ore and nuclear material existing in the Brazilian territory. Currently, CNEN's competences are supported by Law 7781/89 (BRASIL, 1989), which still includes its responsibility for all radioactive minerals existing in the national territory. CNEN's subsidiary, INB is responsible for the exploitation of uranium, from mining and primary processing to the production and assembly of the fuel elements that power the reactors of the nuclear plants. INB also acts in the area of physical treatment of heavy minerals with the prospecting and research, mining, industrialization and commercialization of monazitic sands and obtaining rare earths (JORGE, 2014).

The Federal Constitution of 1988 [3] was very specific in the matter of the Brazilian Nuclear Program, and mainly in the exploration of the existing nuclear ores in the national territory:

Art. 21. The Union is responsible for:

(...)

XXIII - explore nuclear services and installations of any nature and exercise a state monopoly on research, mining, enrichment and reprocessing, industrialization and trade in nuclear ores and their derivatives, in compliance with the following principles and conditions:

a) all nuclear activity in national territory will only be admitted for peaceful purposes and with the approval of the National Congress;

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b) under permission, the marketing and use of radioisotopes for research and medical, agricultural and industrial uses are authorized;

c) under permission, the production, commercialization and use of radioisotopes with a half-life of two hours or less are authorized;

d) civil liability for nuclear damage does not depend on fault;

177. The Union's monopoly consists of:

(...)

V - research, mining, enrichment, reprocessing, industrialization and trade in nuclear ores and minerals and their derivatives, with the exception of radioisotopes whose production, commercialization and use may be authorized under permission, in accordance with paragraphs b and c of item XXIII of the caput of art. 21 of this Federal Constitution. (Wording given by Constitutional Amendment nº 49, of 2006).

Therefore, legally, CNEN is responsible for all natural radioactive anomalies existing throughout the National Territory, including those considered economically unviable, as is the case with the anomaly in the Pernambuco and Pedra de Venturosa cities. Thus, it is the responsibility of CNEN to adopt mitigation measures to remedy or remove the NORM existing on the dairy farms in the cities of Pedra and Venturosa. In addition, according to the law, CNEN itself must be held legally liable for any damages caused to third parties resulting from exposure to natural radiation. Therefore, as a regulatory body for nuclear activities in Brazil, CNEN must create a regulation that legislates on what measures should be adopted in relation to natural radioactive occurrences that have high levels of NORM, including those considered economically unviable.

IV. CONCLUSION

Based on Brazilian laws, the National Nuclear Energy Commission (CNEN), through its subsidiary Nuclear Industries of Brazil (INB), is responsible for the radioactive anomaly that exists in the cities of Pedra and Venturosa, both located in the Agreste Semiarid Region of the State.

CNEN is responsible for establishing mitigation measures for the remediation or removal of NORMs from the area where the radioactive anomaly of the cities of Pedra and Venturosa is located.

CNEN must create a norm of standard procedures that must be applied specifically to cases of natural radioactive anomaly, to avoid third party exposure to high levels of radiation.

CNEN should be responsible for the nuclear damage eventually caused to third parties who are exposed to radiation from natural radioactive anomalies.

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