Is a nuclear catastrophe potentially possible in the Angra 3 plant and what are possible scenarios for this, based on the weaknesses of the planned design and the lessons learnt from Fukushima?

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Author's Background

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1. Summary

In the licensing of Angra 3, Eletronuclear presented inappropriate data and did not assess quantitatively the possible frequencies, consequences and risks for a representative set of accident sequences. This assessment is essential to know the real risks of the project and to plan for realistic emergency scenarios.

Moreover, Angra 3 is an out-dated reactor design and does not comply with several modern security and reactor standards developed after the Three Mile Island accident and the terrorist attacks of September 11, 2001. Angra 3 does not employ the technology available in third generation reactors, like the European pressurized water reactor (EPR), which includes new safety systems such as: a double containment; four redundant active-safety systems separated through four auxiliary buildings, two of

which are aircraft crash protected; a core catcher under the pressure vessel and further safety features.

External events like fires, explosions, terrorism and airplane crashs were not considered by the project. But an airplane crash, sabotage or terrorism, for instance, could without doubt cause fires or explosions beyond the design criteria of Angra 3. The Brazilian reactors are not prepared for these type of events and do not meet the more stringent requirements that were developed following the attacks of September 11, 2001 in New York, nor even the requirements that were developed after Three Mile Island in 1979. Angra 3 also doesn't meet all of the safety requirements applied for its reference reactor Grafenrheinfeld in Germany. Angra 3's containment will be only half as thick as Grafenrheinfeld's, thus providing less protection in case of events like a hydrogen explosion or an airplane crash.

Due to the long time period since the project's inception, Eletronuclear has spent a large sum to store, inspect and maintain the imported reactor components for Angra for more than 20 years. As the sampling criteria used for inspection focus only on the main components, there is the possibility that components not included in the inspections become dysfunctional through aging, which in turn increases the risks at plant start up and in the operational phase.

It is also key to note that the Angra dos Reis site does not meet the criteria that Eletronuclear is using to currently identify suitable sites for future nuclear plants. These exclude the location of nuclear power plants in areas prone to landslides or near densely populated cities. Angra 3, however, is located in an area with unstable slopes and near a densely populated city, Angra dos Reis. The government's new criteria are an inadvertent admission that the Angra 3 site is not suitable for a nuclear power plant.

While earthquakes and tsunamis are extremely rare events, the region between Sao Paulo and Rio de Janeiro, where Angra is located, experiences massive landslides and flooding on a regular basis, leading to power outages, sweeping away and burying buildings, bridges, roads and other infrastructure, often leading the Government to declare a state of emergency for the affected area. If one envisions such a scenario directly hitting the Angra site, it is highly likely that the region's sole access road would be blocked, making it impossible to achieve a prompt evacuation of the local population and impairing access to the reactor for emergency personnel (See also the study by Dr. Celio Bermann[1]). If such an event leads to a prolonged interruption of external power and the destruction of the diesel generation system at Angra, we have the potential for a catastrophe that could even surpass Fukushima, where at least evacuation and access to the site where easier to achieve.

The safety culture in the Brazilian nuclear sector also presents many problems, such as a conflict of interests due to a mixture of responsibilities of its Nuclear Energy Commission (CNEN) and a lack of appropriate supervision in the licensing process of nuclear installations, including a lack of oversight to determine if conditionalities are fulfilled or met in due time. The fact that conditionalities are often not fulfilled at all or experience enormous delays would most likely also increase the consequences of an eventual accident, terrorism or sabotage at the nuclear installations in Angra. To address

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[1] Celio Bermann, 2012 – "Expert Opinion on Safety Aspects of the Angra 3 Nuclear Project", Study commissioned by the German NGOs Urgewald, Greenpeace and Campact.

these problems, the Brazilian regulatory bodies CNEN and IBAMA (Brazilian Institute of Environment and Natural Resources) or their substitutes must be independent of the Brazilian government and the rules, roles and powers of each agency must be clearly defined.

Many factors played a role in the Fukushima accident, but what we ultimately viewed here were the consequences of wrong assumptions, a dangerous site, out-dated reactor technology, an insufficient safety analysis and a lack of oversight through an independent nuclear safety authority. Each of these risk factors is also present in the Angra 3 project and leads to the conclusion that a catastrophic accident scenario is indeed possible for this plant.

2. Flaws in the assessment and licensing process

A large part of the following review is based on technical advice given to IBAMA on the licensing of the nuclear reactor Angra 3 [2].

Eletronuclear developed a partial probabilistic safety assessment (PSA) for Angra 3, based on data from a similar reactor (Biblis B), but didn't consider the differences between the two reactors. Except for a set of scenarios involving conventional risks, Eletronuclear focused only on evaluating the occurrence frequency of the more serious scenarios and improperly used the results of a consequence analysis performed for a reactor located in Germany instead of Brazil! In addition, the dispersion model used was poor compared to modern tools and the treatment of ground topography was inadequate. The study was conducted for 19 flat locations in Germany and not specifically for the hilly Angra dos Reis site in Brazil. All wind directions were considered equally likely and were not based on real meteorological data for the Angra site. This is a completely unacceptable approach. A PSA is not transferable as local characteristics like meteorological conditions and topography determine the dispersion of the radioactive plume; the actual population distribution is key to asessing the social consequences of an accident; the local safety culture (political, manufacturers, servicers, managers, workers etc.) has immense relevance for the development of a catastrophic accident because it is the main cause of incidents, etc.

The PSA used generic data. It was not developed specifically for Angra 3, nor did it consider the experience in the operation of Angra 2, although both plants are identical and have the same operational, environmental and human conditions. In addition, the PSA did not consider the experience with Angra 1. Although this reactor is not identical to Angra 3, it is also a pressurized water reactor (PWR) and has been in operation longer than Angra 2, thus providing data for human factors, which are the most important factors in case of accidents. Eletronuclear has also not assessed the concurrent risks of locating all three reactors (Angra 1, 2 and 3) together, although the experience in Fukushima has shown that the consequences of potential catastrophic accidents due to a common cause may be much higher in such a scenario.

[2] Corrêa, F., 2009 – "Parecer Técnico - Respostas ao Ofício Nº172/2008 COEND/CGENE/DILIC/IBAMA, Unidade 3 da Central Nuclear Almirante Álvaro Alberto – ANGRA 3 ELETRONUCLEAR Processo IBAMA: Nº 02022.002206/99-28".

Eletronuclear did not develop a specific probabilistic safety assessment for Angra 3 to assess quantitatively, for each representative accident sequence, the following types of consequences: total quantity of radioactive material released; number of immediate fatalities; number, type and period of expected delayed fatalities; number of liquidators and people involved in activities aimed at mitigating the consequences of the accident, cleaning, decontamination, evacuation, etc.; radius and area of the exclusion zone in which permanent residence of the population will be prohibited; duration period of the exclusion zone; number of people evacuated from their homes; radius and zone area with lethal doses for flora / fauna; total cost to the company that owns the reactor; total projected longterm costs to country(ies) hit; responsibility for these costs; form of insurance. To do this kind of study should be one of the key lessons learnt from Fukushima.

To properly assess the risks of Angra 3, Eletronuclear must evaluate both the expected and the potential consequences of a representative spectrum of accident scenarios. The cost of this type of evaluation is about one thousandth of investing in the business (or roughly equal to the annual cost borne by the Brazilian government to mitigate the consequences of the radiation accident in Goiania![3]). In the case of Angra 3, the business license was issued without a full assessment of the plant's potential harm to people and the environment.

In addition, there was no comparative safety analysis of different sites for the location of the Angra reactors - instead the site was selected by using military criteria during the last military dictatorship period in Brazil. It is important to point out that the Angra dos Reis site would not pass two of the criteria that Eletronuclear is currently using to identify suitable sites to accommodate future nuclear plants. One criterion eliminates all sites on aquifers, near geological faults and unstable slopes. The other criterion eliminates areas near densely populated cities (more than 50 thousand inhabitants)[4]. By building a new reactor at the Angra dos Reis site, Eletronuclear is violating its own criteria.

The following statement, made by REALNORTE - College of Environmental Entities of the North Coast of São Paulo, sums up the flaws in the locational study for Angra 3[5]: "*Locational alternatives are still justified because they are based on studies conducted by DNAEE 1969, which issued the Decree No. 114 on 13/7/1970, authorizing the installation of the Angra 1 plant in Cunhambebe District, the city of Angra dos Reis in the State of Rio de Janeiro, following the "Guidelines for Choosing Locations for Power reactors," downloaded by CNEN in 1969*[6]*, giving improper and untimely criteria established prior to the 1988 Constitution, which established new areas of discussion and criteria for locational analysis of alternatives and, above all the technical*

[3] Câmara dos Deputados do Brasil, 2006 – "Relatório do Grupo de Trabalho Fiscalização e Segurança Nuclear", Comissão de Meio Ambiente e Desenvolvimento Sustentável, p. 72.
[4] Oliveira, F., 2011 – "Angra não teria usina Nuclear hoje", Ministério da Defesa, Assessoria de Comunicação Social, Resenha Diária do: O GLOBO 15/3/2011, p. 3.
[5] REALNORTE. 2008 – "Manifestação e requerimentos… sobre o licenciamento do reator Angra 3", Colegiado de Entidades Ambientalistas do Litoral Norte de São Paulo, p. 3, www.cunhambebe.org.br/media/QUESTOESaoIBAMA_ANGRA3.doc.
[6] CNEN, 1969 – "Normas para Escolha de Locais para Instalação de Reatores de Potência Resolução CNEN- 09/69, Publicação: D.O.U. de 31/07/69", Resolução 09/69, Junho/1969, Comissão Nacional de Energia Nuclear.

components of risk assessment and impacts that are most relevant to a serious and democratic state of law in which we live today in Brazil. Locational aspects of the installation should especially consider the UFRJ (Federal University of Rio de Janeiro) statements contained, in the same EIA, the landslide mass, associated with the development or deployment of access roads."

Overall, it must be stated that the business license for Angra 3 was issued on the basis of inappropriate data, an incomplete consequence analysis and without a comparative safety analysis of different sites.

This is all the more serious as the Fukushima accident demonstrated that light-water reactors are not immune to nuclear catastrophes classified in the same range of severity as the Chernobyl accident[7], an assertion that the Western nuclear industry had constantly repeated over the past two decades.

The consequences of a catastrophic accident in Angra 3 could not only lead to insolvency of Eletronuclear, but generate costs that exceed even the capacity of the Brazilian government to shoulder the same. The projected costs associated with Chernobyl, for example, amount to hundreds of billions of dollars for each of the main countries impacted[8]. Moreover, the permanent exclusion zone can reach thousands of square kilometers. Similar costs are expected for Fukushima[9].

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3. The Project's Technical Standard

Angra 3 is similar to Angra 2 as-built and thus Angra 2 has been accepted by CNEN as the reference plant for Angra 3. The only major technical alteration planned for Angra 3 is the substitution of the conventional instrumentation and controls with a digital system[10]. However, digital systems are not automatically safer than analog systems, for instance, the highly sophisticated Stuxnet virus was possibly constructed by a nation state to destroy operations at Iranian nuclear installations[11]. According to CNEN, Angra 2 has implemented all the safety related modifications added to the German reference plant Grafenrheinfeld, as well as most improvements built in the KONVOI plant series[12]. However, as explained below, Angra 3 nonetheless presents an outdated technical standard and design.

[7] World Nuclear Association, 2012 – "Fukushima Accident 2011 – (updated 30 January 2012) ", http://www.world-nuclear.org/info/fukushima_accident_inf129.html.
[8] IAEA, WHO, UNDP, FAO, UNEP, UN-OCHA, UNSCEAR, WORLDBANK GROUP, BELARUS, THE RUSSIAN FEDERATION, UKRAINE, 2006 - "Chernobyl's Legacy: Health, Environmental and Socio-Economic Impacts and Recommendations to the Governments of Belarus, the Russian Federation and Ukraine", The Chernobyl Forum: 2003–2005 Second revised version".
[9] World Nuclear Association, 2012 – "Fukushima Accident 2011 – (updated 30 January 2012) ", http://www.world-nuclear.org/info/fukushima_accident_inf129.html.
[10] CNEN, 2011 – "National Report of Brazil for the 4th Review Meeting Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management", Comissão Nacional de Energia Nuclear, p. 18.
[11] Robert McMillan, 2010 – "Was Stuxnet built to attack Iran's nuclear program?", InfoWorld, September 21, 2010.
[12] CNEN, 2010 – "Fifth National Report of Brazil for the Nuclear Safety Convention", Comissão Nacional de Energia Nuclear, P. 13.

Angra 2 was designed to resist the following external events: earthquake, burst pressure wave, TNT explosion, external flooding and high wind speed. However, external events like tornadoes, waterspouts and hurricanes; tsunamis and aircraft crashes were not considered in its design due to their very low occurrence probability[13]. In this context, Angra 3 presents one improvement relative to Angra 2: all class 1 structures (structures that are required for plant shutdown and residual heat removal) are designed to resist the effects of a medium EF3 (Enhanced Fujita scale) tornado[14].

Although the reference reactor for Angra 2 is Grafenrheinfeld in Germany, its containment (as well as the containment of Angra 3) is thinner than in Grafenrheinfeld (60 cm instead of 120 cm[15]) and is thus not equipped to withstand the crash of a small military plane (10 tons and flightspeed of 650 km/h) or the crash of a Boeing 707 at ground approach speed (90 t and speed of 370 km/h)[16]. Eletronuclear has not considered the impact of an airplane crash on the Angra reactors because it has assumed that this event has a low probability of occurrence[17]. The terrorist attacks of September 11, 2001, however, show that it is difficult to exclude the possibility of such an event. The original plan of the terrorists was to highjack ten aircraft and crash into several targets, including nuclear power plants[18]. Although a plane crash scenario may not be likely, it is nonetheless a possible scenario for Angra 3 and it is therefore a serious safety gap that the Angra 3 containment is so much thinner than the German reference-reactor design.

Angra 3 does not employ the technology available in third generation reactors[19], like the European pressurized water reactor (EPR). The EPR includes new safety systems such as[20]: a double containment; four redundant active-safety systems separated through four auxiliary buildings, two of which are aircraft crash protected; a core catcher under the pressure vessel; primary diesel generators with fuel for 72 hours and secondary back-up generators for 24 hours plus tertiary battery back-up lasting 12 hours. It is designed to withstand seismic ground acceleration of 60% of standard gravity g (9.80 m/s^2) without safety impairment.

There are four initial storage facilities at the Angra site for low and medium-level activity solid waste. They were constructed between the years 1981 and 2009 and the

[13] CNEN, 2010 – "Fifth National Report of Brazil for the Nuclear Safety Convention", Comissão Nacional de Energia Nuclear, P. 64.
[14] CNEN, 2010 – "Fifth National Report of Brazil for the Nuclear Safety Convention", Comissão Nacional de Energia Nuclear, P. 64-67.
[15] Ministério do Meio Ambiente, 2001 – "Expansão da Central Termonuclear Almirante Álvaro Alberto: A Conclusão de Angra Iii - Consultas aos Segmentos Sociais Estratégicos", p. 24.
[16] Pinguelli Rosa, L. , Estudo da colisão de um avião com a contenção do reator nuclear, Rev. Bras. de Ensino de Física v 2, n.1, p.4, 1980
[17] Eletronuclear, 2011 – "Critérios de segurança adotados para as usinas nucleares Angra 1, Angra 2 e Angra 3", pp. 15-16.
[18] National Commission on Terrorist Attacks Upon the United States, 2004 – "The 9/11 Commission Report", p. 154.
[19] Eletronuclear, 2012 – "Angra 3 - dados técnicos - Angra 3 é uma usina de última geração?", http://www.eletronuclear.gov.br/SaibaMais/Perguntaserespostas/Angra3dadost%C3%A9cnicos.aspx, page assessed at February 9, 2012.
[20] World Nuclear Association, 2012 – "Advanced Nuclear Power Reactors – (Updated February 2012)", http://www.world-nuclear.org/info/inf08.html.

older one is planned to be remodeled during 2012 [21]. An additional wet storage facility is planned to be constructed by Eletronuclear to complement the current storage-capacity of spent fuel for Angra 1, 2 and 3 on site. The conceptual project started in 2007 and is supposed to start operations in 2017. As the transfer of irradiated fuel to these new pools is planned to start in 2017 for Angra 2 and in 2018 for Angra 1, this project is critical for the continuity of operations of these two reactors. The transfer will initiate in 2030 for Angra 3 [22].

The spent fuel will initially be located in internal ponds inside the containment for Angra 3 [23]. After some time, when the average residual heat-load is 1.0 kW per fuel element (at Fukushima, the heat loads at its pools were a little higher, between 1.5-2.3 kW per fuel element[24]), the spent fuel will be transferred to other pools located externally to Angra 3. Here, it may well stay stored, under an active coolant system, for a period of 60 years. Although these pools will be protected by a concrete containment, Eletronuclear does not provide information on the specifics[25] and this raises the question whether these new pools will be more or less vulnerable to external impacts.

One of the key lessons learnt from the Fukushima events is that the safety of spent fuel in storage must be ensured by the ready provision of make-up water[26], a design basis criterion that is missing for Angra 3. Following a major loss of coolant from leakage or boiling, the residual decay heat of the fuel elements stored in the pools may enable a potentially self-sustaining fire reaction. The reaction between the Zircaloy cladding of spent fuel and water steam produces hydrogen and may lead to an explosion that breaches the containment and leads to a massive release of radioactivity.

Due to the long time period since the project's inception, Eletronuclear has spent a large sum to store, inspect and maintain the imported reactor components for Angra 3 for more than 20 years. As the sampling criteria used for inspection focus on the main components[27], there is the possibility that components not included in the inspections become dysfunctional through aging, which in turn increases the risks at plant start up and in the operational phase. Human error in the maintenance of key components may also pose risks during operation and start up.

The following two quotes are from the engineer Sidney Luiz Rabello, expert on licensing and safety of nuclear power plants at the National Commission for Nuclear Energy (CNEN): 1) "*The Angra 3 project is archaic. It does not include the modern*

[21] CNEN, 2011 – "National Report of Brazil for the 4th Review Meeting Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management", Comissão Nacional de Energia Nuclear, pp. 86-88.

[22] Eletronuclear, 2008 – "Estocagem Inicial de Combustível Irradiado", LAS/ANS, Expo Nuclear Energy Technology Rio 2008.

[23] Eletronuclear, 2011 – "Critérios de segurança adotados para as usinas nucleares Angra 1, Angra 2 e Angra 3", pp. 15.

[24] World Nuclear Association, 2012 – "Fukushima Accident 2011 – (updated 30 January 2012) ", http://www.world-nuclear.org/info/fukushima_accident_inf129.html.

[25] Eletronuclear, 2008 – "Estocagem Inicial de Combustível Irradiado", LAS/ANS, Expo Nuclear Energy Technology Rio 2008.

[26] World Nuclear Association, 2012 – "Fukushima Accident 2011 – (updated 30 January 2012) ", http://www.world-nuclear.org/info/fukushima_accident_inf129.html.

[27] IAEA, 2008 – "Restarting Delayed Nuclear Power Plant Projects", International Atomic Energy Agency, IAEA Nuclear Energy Series No. NP-T-3.4, pp. 71-74.

principles of safety engineering for nuclear power plants of the early 21st century. It does not have the resources to prevent accidents like Three Mile Island (TMI). The new designs of nuclear power plants in developed countries are much safer, and projects such as Angra 3 are no longer accepted in the United States or in Europe. AREVA herself, the designer of Angra 3, does not have in its range of products, nuclear projects from the 70s like Angra 3."[28] 2) "*The safety criteria post-TMI require, among other things, a new design for the building of the Angra 3 reactor with additional requirements for the containment, the last barrier against the release of radioactive material*"[29]

4. Possible Damage Scenarios for Angra 3

4a. Natural Catastrophes

Earthquakes and Tsunamis

Angra 3 was designed to resist an earthquake with a horizontal ground acceleration up to 0,1 g. Its 8 m high seawall is designed to protect the site from 4 m high sea waves[30].

The massive earthquake (magnitude 9 on the Richter scale 100 km off the coast of Japan, and ground accelerations of 0.37g at the reactor's site[31]) and the accompanying 14 m high tsunami that hit Fukushima produced a long-lasting total station blackout for the boiling water reactors (BWR) (Lobscheid, 2011[32]). The batteries ran out and there was no more core emergency cooling. The residual heat in the reactor cores increased the water coolant pressure, thus opening the steam release valves. The nuclear fuel rods became uncovered and overheated. The very high temperatures led to a reaction between the zircaloy cladding and steam, producing hydrogen that was vented to the secondary containment together with radioactive gases, where it eventually exploded. The fuel elements were damaged and dropped to the bottom of the reactor vessel, eventually perforating it and accumulating in the primary containment vessel (NIRS, 2011[33]).

If subjected to an earthquake and tsunami of this magnitude, a pressurized water reactor (PWR) could have resisted a little longer than the boiling water reactors (BWR) at Fukushima because PWRs have some features that would retard the evolution of this chain of events: In contrast to BWRs, pressurized water reactors have a secondary cooling circuit with non-radioactive water which evaporates while absorbing the

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[28] Rabello, Sidney L., 2010 - "O anacronismo de Angra 3", Jornal do Brasil, 5 de fevereiro de 2010.
[29] Rabello, Sidney L., 2010 - "Angra 3 realmente é um projeto obsoleto", Jornal do Brasil, 30 de março de 2010.
[30] Eletronuclear, 2011 – "Critérios de segurança adotados para as usinas nucleares Angra 1, Angra 2 e Angra 3", pp. 9-12.
[31] ENS, 2011 – "High Scientific Council position paper: The accident at Fukushima", http://www.euronuclear.org/e-news/e-news-34/hsc-print.htm.
[32] Lobscheid, C. 2011 – "What Happened In Fukushima - A Technical Perspective - The Nuclear Accidents at the Mark 1 Boiling Water Reactors (BWR) at Fukishima Daiichi Units 1 – 4 and Implications for American BWR", Lawrence Berkeley National Laboratory's Environmental Energy Technologies Division.
[33] NIRS, 2011 – "Chronological Fact Sheet On 2011 Crisis at Fukushima Nuclear Power Plant", Nuclear Information and Resource Service, http://www.nirs.org/reactorwatch/accidents/Fukushimafactsheet.pdf.

residual heat generated in the core through the primary circuit. Without any other type of intervention, this provides some extra time before events develop as they did in the BWRs in Fukushima. Hydrogen explosions are also less likely in a PWR because the containment has igniters and catalysts that burn or recombine hydrogen as soon as it is produced. In addition, the higher volume of the containment of a PWR allows for more time before radioactivity is released into the environment. And the bottom of the reactor vessel of a PWR is not perforated like a BWR (for the passage of the control rods) and will thus take longer to be perforated by the melted core. All this being said however, at the end, the consequences for a PWR would be similar to what happened to the BWRs at Fukushima[34].

Generally speaking, Brazil shows a low level of seismic activity. This is because the country is located in the middle of a tectonic plate and not on its edge. Countries located near the edge of a tectonic plate, like Chile for example, are more prone to large earthquakes due to the interaction with neighboring plates (USGS, 2012 A[35]). This, however, does not mean that Brazil can not suffer a major earthquake. The eastern part of the United States is also located in the middle of a tectonic plate, but out of the fifteen major U.S. earthquakes, four occurred in its eastern region (USGS, 2012 B[36]). Earthquakes in oceanic regions typically generate tsunamis. Although considered a rare event, if a large earthquake occurs in the ocean near the site of Angra 3, its seawall might be overtopped by a tsunami and an event similar to what happened in Fukushima could occur. Furthermore, a tsunami may be generated by events like meteors[37], volcanic eruptions and landslides, which can occur both under and over the sea[38]. One of the world's highest tsunamis, in fact, was caused by a massive landslide into Lituya Bay, Alaska, where it caused a 500 meter high wave[39]. This event shows how in a bay area, even a local tsunami can be really dangerous.

Tornadoes and Waterspouts

Although class 1 structures at Angra 3 are projected to resist the effects of a medium EF3 (Enhanced Fujita scale) tornado[40], there is no mention of waterspouts in the project's documentation. Although studies of tornadoes and waterspouts have only recently commenced in Brazil, they show that Southeastern Brazil (where the Angra site is located) is not immune to these phenomena.

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[34] ENS, 2011 – “High Scientific Council position paper: The accident at Fukushima”, http://www.euronuclear.org/e-news/e-news-34/hsc-print.htm.

[35] USGS, 2012 A – “Seismicity of the Earth 1900-2010”, United States Geological Survey, http://earthquake.usgs.gov/earthquakes/world/seismicity_maps/.

[36] USGS, 2012 B – “Largest Earthquakes in the United States – 48 States”, United States Geological Survey, http://earthquake.usgs.gov/earthquakes/states/10_largest_us.php.

[37] Steven N. Ward and Erik Asphaug, 2003 – “Asteroid impact tsunami of 2880 March 16”, Geophys. J. Int. (2003) 153, F6–F10.

[38] Steven N. Ward, 2001 – “Landslide tsunami”, Journal OF Geophysical Research, Vol. 106, No. B6, pp. 11,201-11,215, 2001.

[39] Tim Folger, “The Calm Before the Wave - Where and when will the next tsunami hit?”, National Geographic, February 2012.

[40] CNEN, 2010 – “Fifth National Report of Brazil for the Nuclear Safety Convention”, Comissão Nacional de Energia Nuclear, P. 64-67.

There were four cases of massive waterspouts on the coast of Rio de Janeiro in recent years: May 24, 2001, February 20, 2005, April 3, 2006, 21 and April 27, 2009[41]. From 1957 to 2007, about 50 tornadoes and waterspouts were recorded only in the State of Sao Paulo in Brazil, some of them with wind speeds over 300 km/h (F3 tornado), which is higher than the wind speed of 45 m/s used for the design of Angra 3[42], and damage higher than US$ 50 million[43]. If a tornado higher than category EF3 hit the Angra 3 site, an event similar to what occurred in Fukushima could eventually happen.

Hurricanes

Due to their very low probability of occurrence, the possibility of a hurricane was not considered in the design of Angra 3[44]. On March 28th 2004, however, Brazil was surprised by a category 1-2 hurricane that crashed into the coast of the State of Santa Catarina[45] producing surface wind speeds up to 44 m/s (almost equalling the maximum wind speed projected for Angra 3) and caused an estimated US$ 425 million of damages[46]. Hurricane Catarina, as it became called, caused flooding, landslides and several deaths as well as significant economic losses to the southern region of the country[47]. While this was the first time that a hurricane was documented in the South Atlantic, scientists predict that Brazil may well experience more hurricanes in the future due to global warming[48]. If such a hurricane hit the Angra 3 site, it could conceivably precipitate a Fukushima-type accident.

Landslides

While earthquakes and tsunamis are extremely rare events, the region between Sao Paulo and Rio de Janeiro, where Angra is located, experiences massive landslides and flooding on a regular basis. Each year during the rainy season, massive mudslides and flooding lead to power outages, sweep away and bury buildings, bridges, roads and other infrastructure, often leading the Government to declare a state of emergency for the affected area. If one envisions such a scenario directly hitting the Angra site (and it seems only a question of time until this happens), it is highly likely that the region's sole access road would be blocked, making it impossible to achieve a prompt evacuation of

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[41] Cardoso, L.F.N., Costa, R.M.A. e Menezes, W.F., 2010 – "Trombas D'água no Rio De Janeiro: Condições Atmosféricas Favoráveis", Universidade Federal do Rio de Janeiro, UFRJ – Instituto de Geociências – Departamento de Meteorologia, http://www.cbmet2010.com/anais/artigos/166_91084.pdf.

[42] CNEN, 2010 – "Fifth National Report of Brazil for the Nuclear Safety Convention", Comissão Nacional de Energia Nuclear, P. 64-67.

[43] Candido, D.H., Nunes, L.H. and Held, G., 2009 – "Impact of Two Severe Storm Systems over Sao Paulo State, Brazil", 5th European Conference on Severe Storms, 12-16 October 2009, Landshut, Germany.

[44] CNEN, 2010 – "Fifth National Report of Brazil for the Nuclear Safety Convention", Comissão Nacional de Energia Nuclear, pp. 64-67.

[45] NASA, page assessed in February 12, 2012 – "The Nameless Hurricane", NASA SCIENCE – Science News, National Aeronautics and Space Administration, USA, http://science.nasa.gov/science-news/science-at-nasa/2004/02apr_hurricane/.

[46] Ron Mctaggart-Cowan et alii, 2006 – "Analysis of Hurricane Catarina (2004)", Monthly Weather Review, Volume 134, American Meteorological Society, p. 3030, November 2006.

[47] Jose A. Marengo, 2009 "Mudanças Climáticas, Condições Meteorológicas Extremas e Eventos Climáticos no Brasil", P. 5, sponsored by Lloyds.

[48] Alexandre Bernardes Pezza and Ian Simmonds, 2005 – "The first South Atlantic hurricane: Unprecedented blocking, low shear and climate change", Geophysical Research Letters, Vol. 32, L15712, 5 PP., 2005.

the local population and impairing access to the reactor for emergency personnel (See also the study by Dr. Celio Bermann[49]). If such an event leads to a prolonged interruption of external power and the destruction of the diesel generation system at Angra, we have the potential for a catastrophe that could even surpass Fukushima, where at least evacuation and access to the site where easier to achieve.

It must be clearly stated that the high probability of landslides and the associated risks make this site unsuitable for a nuclear reactor. The Brazilian Government has, in fact, inadvertently acknowledged this through the criteria it has developed for the siteing of new reactors.

4b. Other External events, like: fires, explosion, terrorism, airplane crash

The design criteria for Angra 3 require that all class 1 structures are able to resist an explosion from a TNT-loaded truck on the road in the vicinity of the reactor. An airplane crash on the site was, however, deemed so improbable that it was not considered in the design of Angra 3[50].

External events like fires, explosions, terrorism and airplane crashs can, however, not be excluded as a possibility. An airplane crash, sabotage or terrorism, for instance, could without doubt cause fires or explosions beyond the design criteria of Angra 3, since the Brazilian reactors are not prepared for these type of events and do not meet the more stringent requirements, that were for example, developed in the USA following the attacks of September 11, 2001[51].

With regard to large aircraft crashes, the Nuclear Regulatory Commission of the USA has set a new rule[52] which added specific design requirements for all new reactors:

"*Each applicant subject to this section shall perform a design-specific assessment of the effects on the facility of the impact of a large, commercial aircraft. Using realistic analyses, the applicant shall identify and incorporate into the design those design features and functional capabilities to show that, with reduced use of operator actions: (A) the reactor core remains cooled, or the containment remains intact; and (B) spent fuel cooling or spent fuel pool integrity is maintained.*"

NRC has ordered that all nuclear power plants develop strategies to mitigate the effects of large fires and explosions that could result from aircraft crashes or other causes. A key provision in the new rule states[53]: "*each licensee shall develop and implement guidance and strategies intended to maintain or restore core cooling, containment, and*

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[49] Celio Bermann, 2012 – "Expert Opinion on Safety Aspects of the Angra 3 Nuclear Project", Study commissioned by the German NGOs Urgewald, Greenpeace and Campact.
[50] CNEN, 2010 – "Fifth National Report of Brazil for the Nuclear Safety Convention", Comissão Nacional de Energia Nuclear, pp. 64-67.
[51] Mark Holt and Anthony Andrews, 2010 – "Nuclear Power Plant Security and Vulnerabilities", CRS Report for Congress, Prepared for Members and Committees of Congress, Congressional Research Service 7-5700 RL34331.
[52] Nuclear Regulatory Commission, 2009 – "Consideration of Aircraft Impacts for New Nuclear Power Reactors", Final Rule, 74 Federal Register 28111, June 12, 2009. This provision is codified at 10 CFR 50.150.
[53] Nuclear Regulatory Commission, 2009 – "Power Reactor Security Requirements", Final Rule, 74 Federal Register 13925, March 27, 2009.

spent fuel pool cooling capabilities under the circumstances associated with loss of large areas of the plant due to explosions or fire, to include strategies in the following areas: (i) Fire fighting; (ii) Operations to mitigate fuel damage; and (iii) Actions to minimize radiological release".

In addition, NRC requires that the design basis threat (DBT) corresponds to the general characteristics of adversaries that nuclear plants and nuclear fuel cycle facilities must defend against to prevent radiological sabotage and theft of strategic nuclear material[54].

5. Nuclear Safety Culture in Brazil

The Brazilian Nuclear Program encompasses under the Brazilian Presidency (see Figure 1), the Development Committee of The Nuclear Program and five ministries: Science and Technology (MCT), Mines and Energy (MME), Defense (MD), Education (MEC) and the Foreign Office (MRE). CNEN (Nuclear Energy Commission), INB (Brazilian Nuclear Industries) and NUCLEP (Industry of Heavy Equipments) are under the Ministry of Science and Technology. Eletronuclear, the owner of the commercial nuclear reactors in Brazil, is under the Ministry of Mines and Energy. The nuclear military program to develop nuclear powered submarines is under the Ministry of Defense[55].

CNEN exerts the Brazilian Government monopoly to mine radioactive elements, produce and trade nuclear materials. CNEN establishes radiation protection standards, regulations and licenses, and supervises and controls all the nuclear activities in Brazil. CNEN also develops research on the use of nuclear techniques. According to CNEN, its mission is: "To ensure safe and peaceful use of nuclear energy, develop and deliver nuclear and related technologies, for the well being of the population".

INB, which is in fact part of CNEN (Figure 1), operates the uranium production chain, from mining to production of the fuel that powers the nuclear reactors in Brazil. Consequently, CNEN has commercial interests as a supplier of the same reactors it regulates and for whose operator, Eletronuclear, it issues licences. This legal conflict of interest allows CNEN to circumvent Brazilian law. For instance, CNEN's research institutions (Figure 1) are regularly contracted to develop studies and research on accident analyses for commercial nuclear installations at INB or Eletronuclear; then these studies are verified by CNEN to issue licenses. For instance, CNEN provided the operating license to the uranium mine at Catité in 2010, but did not suspend it afterwards even though CNEN publically recognized several serious problems[56]. NUCLEP, the company that produces heavy equipment for the nuclear industry, is also part of the CNEN structure (Figure 1).

CNEN's governance structure does not reflect the regulatory independence required by the international convention on nuclear safety (CNS) that was adopted in 1998 by the

[54] Mark Holt and Anthony Andrews, 2010 – "Nuclear Power Plant Security and Vulnerabilities", CRS Report for Congress, Prepared for Members and Committees of Congress, Congressional Research Service 7-5700 RL34331.
[55] CNEN, 2010 – "Programa Nuclear Brasileiro – Informações gerais", http://www.cnen.gov.br/acnen/pnb/Palestra1-Programa-Nuclear-Brasileiro.pdf.
[56] Sérgio Rezende, 2011 – "O caso CNEN, por Sérgio Rezende", Luis Nassif Online, http://www.advivo.com.br/blog/luisnassif/o-caso-cnen-por-sergio-rezende.

national congress in Brazil (Decreto legislativo 4 de 22/01/1997 e decreto 2648 de 01/07/1998). Article 8 of the convention says that each signatory country shall:

"*Article 8 - Regulatory Body; Item 2: Each Contracting Party shall take the appropriate steps to ensure an effective separation between the functions of the regulatory body and those of any other body or organization concerned with the promotion or utilization of nuclear energy*". Although the Convention on Nuclear Safety was signed by Brazil in September 20, 1994 [57] , the Government has failed to address this problem. The Brazilian Society of Physics has thus criticized the current state of affairs and is demanding that an independent agency monitor the nuclear program.[58]

There is political interference in all these governmental agencies and companies through the nomination of their executives. For instance, each CNEN president is automatically also the chairman of INB's Board of Directors.[59] As the politicians' appetites increase, more and more lower executive positions are occupied by their political protégés. This fact produces a sense of safety loss among many of the serious scientists and engineers which work for these institutions and companies.

As a result, the nuclear safety culture in Brazil has been less than adequate, as the following examples show:

- Lack of transparency - Eletronuclear hid from the press and society information about the leak of 22,000 liters of radioactive water from the Angra 1 nuclear plant in May 2001[60].
- Lack of transparency - Since the granting of authorization for permanent operation of the Catité uranium mine, several incidents at the facility were not reported to CNEN by INB, such as solvent overflow and pipe breaks causing dispersion of liquid containing uranium and collapse of parts of the slope of the open pit. These events only came to light through reports of resident inspectors from CNEN or the local population[61].
- Non-compliance – INB utilized tailings ponds forbidden by CNEN at the Catité uranium mine[62].
- Non-compliance – INB has no ability to produce the annual environmental monitoring at the Catité uranium mine [63].

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[57] IAEA, page assessed in February 20, 2012 – "Convention on Nuclear Safety", http://www-ns.iaea.org/conventions/nuclear-safety.asp.

[58] Sociedade Brasileira de Física, page assessed in February 20, 2012, "Comissão quer agência independente para fiscalizar programa nuclear", http://www.sbfisica.org.br/v1/index.php?option=com_content&view=article&id=312:comissao-de-fisicos-quer-agencia-independente-para-fiscalizar-programa-nuclear&catid=93:junho-2011&Itemid=270.

[59] INB, Page assessed in February 23, 2012 – "Organizational Structure", Nuclear Brazilian Industries, http://www.inb.gov.br/inb_eng/WebForms/Interna2.aspx?secao_id=6.

[60] O Estado de São Paulo, 2001 – "Prefeito não foi avisado sobre vazamento na usina Angra I", 24 de Setembro de 2001, http://www.estadao.com.br/arquivo/cidades/2001/not20010924p20967.htm.

[61] Sérgio Rezende, 2011 – "O caso CNEN, por Sérgio Rezende", Luis Nassif Online, http://www.advivo.com.br/blog/luisnassif/o-caso-cnen-por-sergio-rezende.

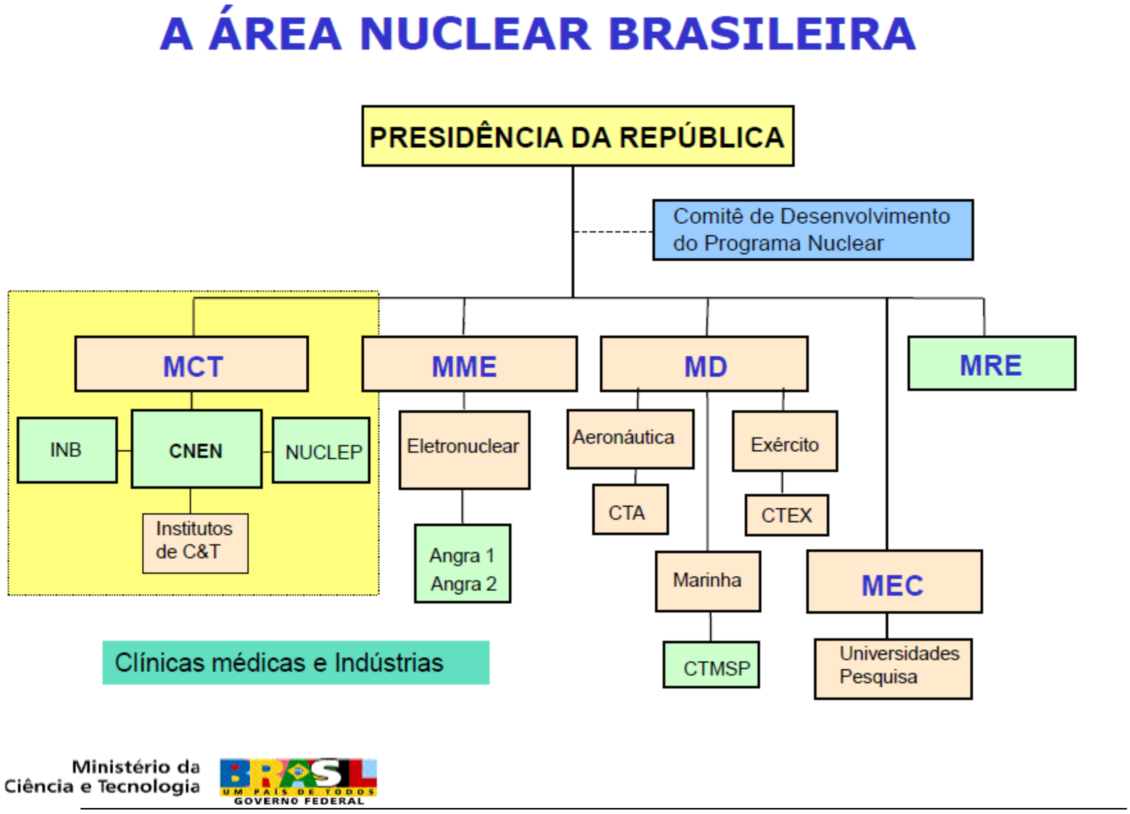
[62] Sérgio Rezende, 2011 – "O caso CNEN, por Sérgio Rezende", Luis Nassif Online, http://www.advivo.com.br/blog/luisnassif/o-caso-cnen-por-sergio-rezende.

[63] Sérgio Rezende, 2011 – "O caso CNEN, por Sérgio Rezende", Luis Nassif Online, http://www.advivo.com.br/blog/luisnassif/o-caso-cnen-por-sergio-rezende.

- Non-compliance – For ten years now, the nuclear reactor Angra 2 has been operating without a permanent license[64][65].
- Lack of safety culture - Eletronuclear refused to shut down the nuclear power plants Angra 1 and 2 on January 3, 2010 as had been requested by the Mayor of Angra dos Reis City, on account of the obstruction by mudslides of the main route of escape in case of a nuclear accident.

The main action needed to address the many deficiencies of the nuclear safety culture in Brazil is the creation of a nuclear regulatory agency really independent of the Brazilian government and of politicians. While there were plans for creating a new and independent regulatory agency, they have been on hold now since several years[66].

Figure 1 – Structure of the Brazilian Nuclear Authorities[67]



6. Effectiveness of the set conditionalities to address safety risks

The law in Brazil is clear when it says: "*Licensing of establishments designed to produce nuclear materials or use of nuclear energy and its applications will be up to the National Nuclear Energy Commission (CNEN), on the advice of IBAMA, hearing the organs of state or local environmental control*". IBAMA is the Brazilian Institute of

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64 Alexandre Gaspari e Rodrigo Polito, 2012 – "Técnica versus política", Brasil Energia, Fevereiro de 2012.
65 Sérgio Rezende, 2011 – "O caso CNEN, por Sérgio Rezende", Luis Nassif Online, http://www.advivo.com.br/blog/luisnassif/o-caso-cnen-por-sergio-rezende.
66 Câmara dos Deputados do Brasil, 2006 – "Relatório do Grupo de Trabalho Fiscalização e Segurança Nuclear", Comissão de Meio Ambiente e Desenvolvimento Sustentável, pp. 45-91.
67 CNEN, 2010 – "Programa Nuclear Brasileiro – Informações gerais", http://www.cnen.gov.br/acnen/pnb/Palestra1-Programa-Nuclear-Brasileiro.pdf.

Environment and Natural Resources, a governmental agency linked to the Environment Ministry. There is, however, an ambiguity on the licensing of nuclear installations since CNEN licenses, under the opinion of IBAMA, in the form of Decree 99274/00 and, at the same time, IBAMA licenses, on the advice of CNEN, in the form of Resolution CONAMA 237/97[68].

The license for the construction of the Angra 3 reactor was granted by IBAMA on March 4, 2009 with 44 conditionalities[69], and by CNEN in May 31, 2010 with 30 conditionalities[70] which will, however, take a long time to be accomplished. Some of the most critical conditionalities include: revision of the risk analysis study as explained in chapter 2 above; continue the study of slope stability and landfill at the site; monitor the traffic conditions of BR-101 and demand the necessary maintenance from the responsible state agency; initiate conventional atmospheric monitoring at the site; initiate the licensing process of a nuclear repository for waste of low and medium activity with CNEN before the start of operation of Unit 3; design and begin implementation of the project approved by the environmental agency for disposal of radioactive waste of high activity before the start of operation of Unit 3; integrate all the results obtained during the monitoring of biota conducted for the two plants in operation, concluding in an analytical way, the current situation of impacted ecosystems and predicting a future scenario of these ecosystems with the installation of Unit 3; hire a laboratory accredited under ISO 17.025 and independent of Eletronuclear to monitor the environment.

Even though the environmental ministry only granted the construction license with “hard" conditionalities stating that they will strictly control implementation, the practice shows that oversight of the nuclear sector at Angra is completely inadequate.

According to IBAMA’s president, Curt Trennepohl[71], and former CNEN’s president, Odair Dias Gonçalves[72], Angra 2, operating since the year 2000, is still running on temporary licenses, as there is still a TAC (Term of Adjustment of Conduct), and IBAMA and CNEN can not provide the final operating license until there is compliance with a series of conditions, like: adaptation of the escape route BR 101, evacuation plans for the range 3-5 km, expansion of the domestic waste dump for Angra 2 etc[73].

Although IBAMA says that all agencies, including CNEN, agree that all conditionalities for Angra 2 were already fulfilled since the year 2006, the Federal Public Ministry, on the other hand, says that there are no documents proving that conditionalities were fulfilled, for instance, proper dimensioning and maintenance of the precarious emergency route (BR-101). According to the Public Ministry, other demands not fulfilled include: implementation of environmental monitoring programs for:

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[68] Câmara dos Deputados do Brasil, 2006 – “Relatório do Grupo de Trabalho Fiscalização e Segurança Nuclear”, Comissão de Meio Ambiente e Desenvolvimento Sustentável, pp. 90-91.
[69] Lorenna Rodrigues, 2009 – “Ibama concede licença de instalação para Angra 3, mas impõe 44 condições”, Folha Online, March 4, 2009.
[70] Mônica Ciarelli, 2010 - “CNEN: licença a Angra 3 permite início de obras”, Agência Estado, 31 de maio de 2010.
[71] Alexandre Gaspari e Rodrigo Polito, 2012 – “Técnica versus política”, Brasil Energia, Fevereiro de 2012.
[72] Sérgio Rezende, 2011 – “O caso CNEN, por Sérgio Rezende”, Luis Nassif Online, http://www.advivo.com.br/blog/luisnassif/o-caso-cnen-por-sergio-rezende.
[73] ANDRE AMARAL, 2009 – “Financing Brazilian Nuclear Programme: A Risky Investment”, October 2009.

wastewater, industrial and sanitary effluents, and atmospheric emissions; environmental restoration program for the Village Residential Mambucaba; preservation program of Mangrove Beach; installation of center of environmental studies; recovery of degraded areas during construction at the site.[74]

The Vice General Attorney of the Republic and Coordinator of the 4th Board of Coordination and Review of the Federal Public Ministry, Mr. Mário José Gisi made the following comments regarding the TAC of Angra 2: a) "*Can the plant operate under these conditions (without an adequate emergency route)? I think not. If Eletronuclear says it has no responsibility on BR-101, and the Federal Government is not doing the proper maintenance on it, then the reactor should be disabled until there is a possibility to use the regular road to escape the place*"; and b) "*can you grant a license for permanent operation if there is no definitive definition for the storage for the nuclear waste?*".[75]

The reality of the nuclear culture in Brazil is that conditionalities are set to give the illusion of safety, but as soon as a construction or operation permit is obtained, these safety conditionalities are often delayed, ignored or forgotten. Although it violates Brazilian nuclear regulations, it has nonetheless become common practice for the authorities to keep on extending temporary licenses and thus enable operators to avoid fulfilling safety requirements. In the case of Angra, this practice could lead to a tragedy: if for example an emergency evacuation is demanded, the lack of a viable escape route means that a large number of inhabitants will be exposed to nuclear radiation.

Conclusion:

The tragic accident in Fukushima was not unavoidable. It can be seen as a consequence of wrong assumptions, a dangerous site, outdated technology, an insufficient safety analysis and a lack of nuclear safety culture and stringent oversight. As planned, Angra 3 does not heed the lessons of Fukushima. It presents many risk factors that make it impossible to exclude the possibility of an accident of comparable magnitude in this facility.

[74] Câmara dos Deputados do Brasil, 2011 – "Debate sobre a segurança do programa nuclear brasileiro", Comissão de Meio Ambiente e Desenvolvimento Sustentável.
[75] Câmara dos Deputados do Brasil, 2011 – "Debate sobre a segurança do programa nuclear brasileiro", Comissão de Meio Ambiente e Desenvolvimento Sustentável.