RADIOPROTECTION ASPECTS IN SITE SELECTION FOR INSTALLATION OF NEW POWER REACTORS IN BRAZIL

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ABSTRACT

This paper approaches the criteria used in order to define the location for installation of new power reactors in Brazil, observing the optimization proceedings of radiation protection, depending on the type of reactor to be installed. The aspects to be considered are: • economic criteria: for example, infrastructure, including: distances between generators and consumer centers of electricity; • geographic criteria: for instance, population density, area, Indian reserves and historical interest areas; • environmental criteria: such as biomes, ecosystems and species occurrence, reserves and national parks; • socio-economic criteria: including the likely impacts of the installation of reactors in productive activities (industry, agriculture, tourism, services) and benefits that can be raised due to new jobs, potential recovery of the savanna and improvements on the transport system; • hydrographic criteria: such as availability of water for cooling and conditions of reusing the same water; • cultural criteria: for example, the presence of historical sites of indigenous or Afro-origin peoples.

1. INTRODUCTION

Currently, compliance with annual dose limits established by national and international standards are not enough to meet radioprotection requirements, since it is necessary to maintain the values of radiation doses as small as reasonably achievable, considering economic and social factors.
This process of reduction of individual doses to an acceptable value is known as a process of optimization of radiological protection or ALARA process (As Low as Reasonably Achievable).

To define the criteria used in selecting a location for installation of new power reactors in Brazil, the necessary perspectives to process the optimization of radiation doses to workers and the general public, depending on the type of reactor to be installed, the following aspects were considered:

- economic and infrastructure, including: distance between generator centers and electricity consumers;
- geographic, including: population density, surface, Indian reserves and areas of historical interest;
- environmental, including: biomes, ecosystems and species occurrence, reserves and national parks;
- socio-economic, including: likely impacts of the installation of reactors in productive activities (industry, agriculture, tourism, services) and benefits that can be raised due to new jobs, potential recovery in the scrub and road system improvements;
- hydrographic, including: availability of water for cooling and conditions of reuse;
- cultural and historical sights and the presence of indigenous peoples and Afro-origin people.

Since southeastern Brazil has already two reactor in operation and one under construction, we chose, as an example for this work, a northeastern state, with priority on its development in this region of the country.

2. DESCRIPTION OF THE CHOSEN STATE TERRITORY

In choosing a northeastern state, the development needs in relation to its neighboring states, the need of electricity, its nearby states and the position not far from other plants, already planned, were considered. Undoubtedly, more nuclear power plants in the north of the northeastern region, in addition to what is being proposed in this paper, will be needed.

In the Northeast, Sergipe was chosen because of its population, land area and density data, which are found in Table 1.

Table 1

State*	Capital*	Capital Population*	State Area*	State Population*	Populacional* Density
Alagoas	Maceió	896.965	27.768	3.037.103	109
Bahia	Salvador	2.892.625	564.693	14.080.654	25
Ceará	Fortaleza	2.431.425	148.826	8.185.286	55
Maranhão	São Luiz	957.515	331.983	6.118.995	18
Paraíba	João Pessoa	674.762	56.440	3.641.395	65
Pernambuco	Recife	1.533.580	98.312	8.485.386	86
Piauí	Teresina	779.939	251.529	3.032.421	12
Rio Grande do Norte	Natal	774.230	52.797	3.013.740	57
Sergipe	Aracaju	520.303	21.910	1.939.426	89

Vegetation

The state of Sergipe vegetation, now greatly modified by man, comprises the **rain forest**, the **savanna** and the **"caatinga".** The rain forest covered the eastern facade, to which it lent the name of forest zone. The "agreste" (wilds), transition forest vegetation to a drier climate, covers the center of the state. The caatinga is developed in the western portion.

Hydrography

Sergipe territory rivers belong to two hydrographic basins: the São Francisco and the Northeastern. Only the first basin has good hydro potential. The second consists of lowland rivers, of which the four main ones are the rio Real, the Piaui, the Vasa-Barris, surrounding the capital, and the Sergipe. All of them flow into the Atlantic Ocean in large estuaries and allow navigation of small vessels.

Population

The inhabitants of the state are concentrated in the area of the forest and in the "agreste" (wilderness). More than half of the population lives in urban centers. In table 2, the 15 most populous cities in the state and two sites of interest to this work are shown, with their relative position within the state population.

Tabela 2 – The 15 most populous cities in the State plus two sites of interest.

Position	Municipality	Population
1	Aracaju	570937
2	Nossa Senhora do Socorro	160829
3	Lagarto	94852
4	Itabaiana	86981
5	São Cristovão	78876
6	Estância	64464
7	Tobias Barreto	48039
8	Itabaianinha	38886
9	Simão Dias	38724
10	Nossa Senhora da Glória	32514
11	Poço Redondo	30877
12	Capela	30769
13	Itaporanga d´Ajuda	30428
14	Propriá	28457
15	Porto da Folha	27124
19	Canindé de São Francisco	24693
24	Carira	19900

The state territory is within the limits of influence of two cities: Salvador and Recife. Aracaju, in addition to be the political and administrative capital, is the economic center of the state. Its influence is felt throughout the state area.

Economy

Agriculture and livestock

The main agricultural products of the state are orange, "agreste" own exportation crop; sugar cane, traditionally grown in the area of the forest; cassava, which, grows in the "agreste", though it appears scattered in other regions and it is used for the consumption of local rural populations, and "coco-da-baía, of which Sergipe is one of the largest domestic producers. There are, also, some other important crops: beans and corn and, to a lesser extent, rice, tree cotton (main product of the countryside) and tobacco. To address the problem of drought, the government invested in the development of

small rural properties, which play a vital role in food production and implemented systems of aqueducts, dams, reservoirs, wells, “cacimbas” (dense fog) and tanks, besides incentivating the plantation of crops and the raising of animals resistant to drought.
The statewide herd has greatly increased. The existence of a modern refrigerating warehouse in the capital contributes to this development. The livestock sector has expanded not only in the “agreste” but in the seaside and in the hinterland (“sertão”), as well.

Industry and mining
The industrial activity is concentrated in Aracaju (food products, textiles and processing of agricultural products). Besides the capital, the industry is also present in Estância and São Cristóvão, textile centers. A cement plant in Aracaju supplies the state consumption. Among the industries in the food sector, there is the production of coconut milk and canned grated coconut.
The development of Sergipe was stimulated by the implementation, since the 1960s, of the industrial district of Aracaju, in an area connected to the main highways. The state is among the largest oil producers in the country. The exploration is done both on the continent (Carmópolis, Siririzinho, Riachuelo and others) and on the continental platform. Since 1985, the first national potassium mine operates in the state. Sergipe has, also, large magnesium, salt and sulfur reserves.
The state chloride-chemical pole integrates the various processing industries of mineral raw materials, such as oil, gas, potassium, granite, halite, sylvinite, carnalite, limestone and sulfur reserves.

3. CHOICE OF THE NUCLEAR POWER PLANT LOCATION

Choosing a likely place for the nuclear power plant, the following premises were analyzed:
Location by the sea or a river, to ease the cooling process. In case it was near the sea, desalinated water could be used for irrigation and salt could be used in food, since the ocean water has about 36g of salt per liter of water.
The central building should be close to the infrastructure of the electric power transmission to facilitate the consumption and prevent transmission losses. On the other hand, it should be far from cities with high population density, to avoid high collective dose, which would increase the cost of installing the extra shielding. It should also be located away from major industrial centers, in order not to damage facilities, in cases of accidents. But, it would be beneficial whether it could be near an agricultural developed region, to take advantage of the refrigerated water used for agricultural irrigation.
The three sites chosen were:
Carira, located near the Sergipe river, about 25 miles northwards, in the very Caatinga. In the state of Sergipe, the caatinga biome coverage occupies the west of the state and reaches the municipalities presented in table 3, along with their position within the state population.

Table 3- A probable location of the reactor, 25 km north from Carira.

Position	Municipality	Population
7	Tobias Barreto	48039
10	Nossa Senhora da Gloria	32514
11	Poço Redondo	30877
15	Porto da Folha	27124
16	Laranjeiras	26903
19	Canindé de São Francisco	24693
22	Poço Verde	21968
37	Monte Alegre de Sergipe	13621
43	Gararu	11458
52	Pirambu	8369
60	Pinhão	5973
61	Graccho Cardoso	5648
64	Itabi	4972

The second location would be on the São Francisco River, between Xingó hydro-electric and Paulo Afonso, near Alagoas and Bahia States plus Canindé do São Francisco municipality. Also, nearby, there are the cities of Curituba and Curralinho, still in the Caatinga.

There is a proposal to make a national park, Cânions de São Francisco, whose location covers: Xingó Power Plant region and its surroundings, with an approximate area of this park of 30,500 ha, covering the municipalities of: Delmiro Gouveia / AL / and Olho D'água do Casado / AL, Piranhas / AL, Paulo Afonso / BA and Canindé do São Francisco / SE.

There is, also, the proposed area of the "sertão" environmental protection, Carrasco, located in the Region of Xingó Power Plant and its surroundings, with an approximate area of Environmental Protection of the Hinterland of Carrasco with 251,280 ha, covering the municipalities of: Delmiro Gouveia / AL, Olho D'água do Casado / AL, Pão de Açucar / AL, Piranhas / LA, São José da Tapera / AL, Paulo Afonso / BA, Sant Brígida / BA, Canindé the San Francisco / SE, Poço Redondo / SE and Porto da Folha / SE.

If any of these two proposals were put in practice, this would favor the location of the reactor for the second choice, once, in terms of security, there would be the existent park security, the park maintenance staff and only some visitors, with a very small collective dose risk.

The third location could be near the coast of Alagoas, in the municipality of Pacatuba, where there is low population density. The third advantage of this site is that, in addition to water for irrigation, there would be, also, the salt for consumption. Another advantage is that it is within an environmental protected area, the northern coast, established by the Decree No. 22995 of November 9, 2004, comprising a length of about 473.12 km ²: the area is located in the municipalities of Pirambu, Japoatã, Pacatuba, Ilha das Flores and Brejo Grande

4. POWER TRANSMISSION NETWORKS OF HIGH VOLTAGE NEAR THE BRAZILIAN COAST AND THE STATE OF SERGIPE.

On Chesf map, we are informed that the company invests in the Northeast more intensively. It has one of the largest power transmission systems in high voltage in Brazil. There are over 18,000 km of 500, 230, 138 and 69 kV lines, combined with a processing capacity of nearly 30,000 MVA in its 94 substations. A set of facilities ensures the interconnection of the transmission network of the Company with other companies that are part of the integrated functioning circuit of the Brazilian electric system.

The routes of growth allow the transfer of energy between the North, Southeast and Midwest that contribute to the reinforcement of electricity supply in the Northeast. It is possible to see, on the map above, that the state of Sergipe has a junction of the different transmission lines, what would result in lower transmission costs.

5 DISCUSSION ON THE MAIN TYPES OF REACTORS.

IAEA DATA: The classification of the types of power nuclear reactors in use worldwide, in April, 2010:

Operational Type	No. of Units	Total MW(e)	Fuel	Enrichment	Moderator	Coolant	Country of origin
BWR	92	83951	UO2	2% a 4%	H2O	H2O (fervente)	EUA
FBR	1	560	UO2 + PuO2			Na0 líquido	Vários
GCR	18	8949	Metalic U		Graphite	CO2	United Kingdom
LWGR	15	10219					
PHWR	46	22840	UO2		D2O	D2O	Canada
PWR	266	245487	UO2	2% a 4%	H2O	H2O	USA
Total:	438	372006					

This type of reactors, denominated pressurized heavy water reactor (PHWR) is also usually called CANDU (an acronym for "Canadian Deuterium Uranium").
Currently, all nucleus-installed capacity in Canada consists of PHWR reactors, which had some units exported to India, Argentina, Romania, South Korea, Pakistan and the Popular Republic of China.
The extremely low value of the cross section for radioactive capture of thermal neutrons by heavy water (1.06 mb / molecule) makes it an excellent moderator for thermal reactors, which can also be used as a coolant. Moderated reactors and heavy water cooled may be fueled with natural uranium and have good neutron economy. These features provide: low fuel costs, good conversion rates and high rates of fuel combustion.
A disadvantage of heavy water is the very high cost to produce it, fact that makes important to avoid losses in pipes and heat exchangers. Another disadvantage is the critical temperature of heavy water, limiting the maximum temperature of the coolan, which has to be submitted to very high pressures. It should be noted that, because of this limitation, the thermodynamic characteristics of water-cooled reactors and heavy water cooled reactors are very similar.
The use of metallic sodium as a coolant in nuclear reactors has a number of disadvantages:
The melting point of this metal is 98 ^{0}C, what requires the reactor to be maintained above this temperature, when shut down.. This drawback can be overcome by the use of a sodium-potassium eutectic alloy (containing 78% and 22% potassium sodium), with a melting point equal to -11 ^{0}C.
The most serious problem, however, is the fact that sodium metal reacts chemically violently, with air and especially water, what makes the structural integrity of components, such as pipes and heat exchangers, absolutely essential. Another problem is the production of radioactive waste and oxides.

Therefore, the choice would be either a PWR or a BWR reactor, which have the largest number of units worldwide.

6. CONCLUSION

Due to the fact that Sergipe has a small population density, it is an excellent strategic location, believed to be the best northeastern state to have the first power reactor installed.
Base on what was previously stated, we consider that the three proposed locations are the best options, with the lowest implantation and implementation costs.