SOCIAL, ECONOMIC AND ENVIRONMENTAL ASSESSMENT OF ENERGY AND WATER DESALINATION OPTIONS FOR THE BRAZILIAN POLYGON OF DROUGHT USING THE IRIS REACTOR

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ABSTRACT

The paper discuss a project conceived to perform a social, economic and environmental assessment of the use of the IRIS Reactor for electricity generation and water desalination in the most dry region of Brazil, the “Polygon of Drought.” The project is financed by the Fund of Energy of the Brazilian Council on Research and Development (CNPq) of the Brazilian Ministry of Science and Technology (MCT), and it will be performed by the Federal University of Pernambuco (UFPe) and the Energetic and Nuclear Research Institute (IPEN) of the Brazilian Nuclear Energy Commission (CNEN). The project will provide comparisons between nuclear and gas options. The final objective of the project is to offer effective evaluations considering the total costs (direct and externalities) of the different energy options and also the associated social and environmental aspects.

1 INTRODUCTION

The well known “Brazilian Polygon of Drought” needs options to cope with the supply of two basic needs that are indispensable thrusts to promote improvements in the quality of life of its population: electric power and water for human consumption, agriculture and industry. An effective approach to solve these problems can attract investments resulting in a sustainable development for the region, one of the most populous areas of Brazil. Appropriate policies and strategies are necessary for this. The development of such vast area should be based on economical, social and environmental precepts.

The lack of large water sources in the region has been one of the greatest difficulties. Also there is no abundance of fossil resources or natural gas. Alternative sources, such as solar and wind energy, can play an important role but they are dependent on favourable local conditions and are still excessively expensive for large scale use.

The objective of this article is to describe a project for social-economic and environmental evaluation of the use of an advanced nuclear reactor for electric power generation and production of drinkable water in the “Polygon of Drought.” The project was originally conceived in the Nuclear Engineering Centre of IPEN-

CNEN/SP. In this article, scenarios are analysed with respect to the social aspects related to the energy, water and environment and a roadmap describing the foreseen activities for the next two years is presented.

2 SCENARIO

2.1 Electricity

Progress is directly associated with energy availability, especially in the form of electricity. This association is so strong that a night image of the Earth seen from the space shows the disparity in the demand of energy for illumination between North and South America, directly associated to the different level of development.

Fig. 1 also illustrates the room for growth in the electric power production in Brazil and shows that the progress in the Northeast region is concentrated on the coastline.

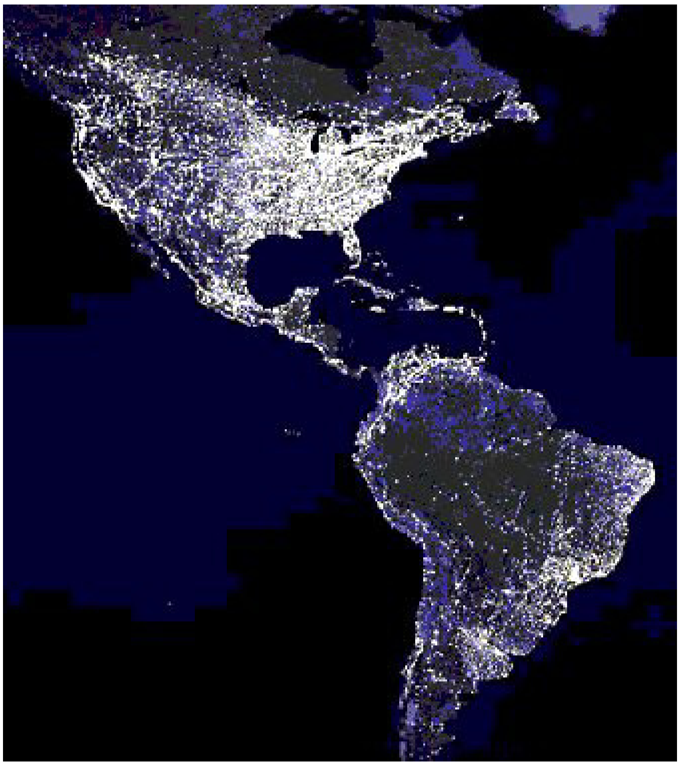

Figure 1. Night image of the Earth [GIF-002-00, 2002][1].

Table 1 presents the evolution of the electric demand in each one of the states of the Northeast Region, from 1984 to 1996. The percentages exhibit the accelerated growing rate and the absolute values demonstrate the room for growth.

Table 1. Evolution of electric demand in the states of the Northeast (kWh/inhab year)

	1984		**1996**		**Growing Rate (%)**	
	Home	*Total*	*Home*	*Total*	*Home*	*Total*
AL	106	867	224	1280	6,4	3,3
BA	112	943	202	1180	5,1	4,2
CE	100	329	218	660	6,7	6,0
MA	60	308	147	1447	7,7	13,8
PB	91	311	206	654	7,1	6,4
PE	137	652	287	863	6,3	2,4
PI	71	195	182	404	8,2	6,3
RN	106	401	257	983	7,7	7,8
SE	140	730	261	1192	5,4	4,2

ONS, the Brazilian National Electric System Operator, predicts very high rates of electric demand growth for the northeast (Table 2). These rates highlight the room for a massive increase in the electric generation park.

Table 2. Evolution of electric demand in the states of the Northeast (growth rate %/year)

	Reference market	High Market
2004	8,4%	10,1%
2005	5,0%	7,0%
2006	5,1%	6,6%
2007	8,8%	7,8%
2008	5,5%	5,9%

Besides this room for improvement, it is important to analyse the international scenarios projected for the 21st Century by IPCC (Intergovernmental Panel on Climate Change). The IPCC reported forty different scenarios in its *Special Report on Emissions Scenarios* (SRES)[2]. These scenarios may be grouped into four large representative groups: A1, A2, B1 and B2. Each one of these groups represents different levels of demographic, social, economical, technological and environmental development. Fig. 2 represents the driving forces for each one of these groups.

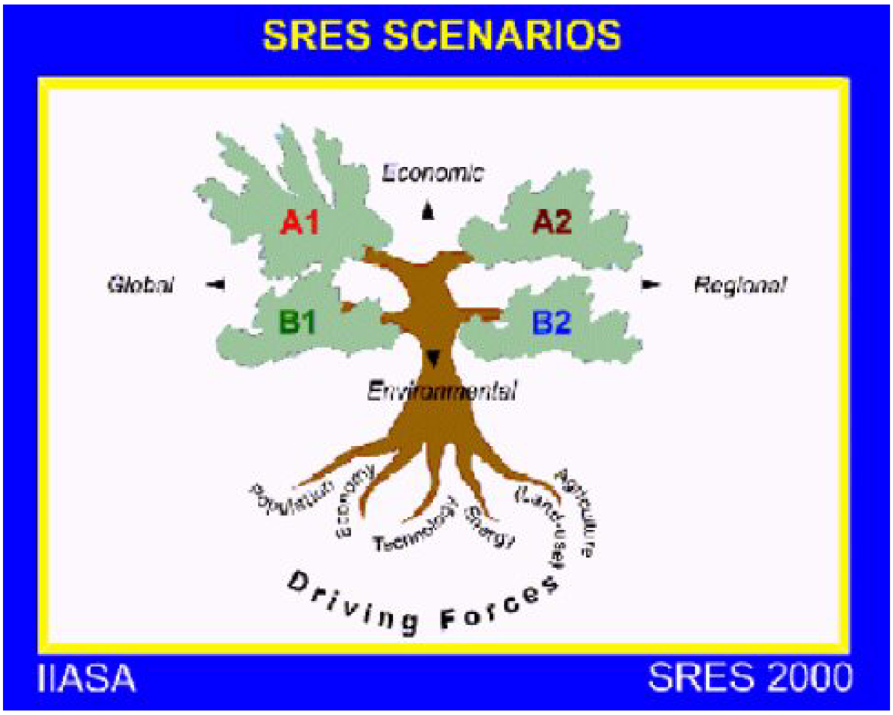

Figure 2. Groups of Energy Scenarios

The economical objectives are the attractors in the branches A, in the top of the Fig. 2, while the environmental objectives dominate the branches B. The branches A1 and B1 incorporate strong globalisation tendencies and a larger international integration, while branches A2 and B2 characterize the regionalism instead of the globalisation tendency.

Branch A1 and its family of scenarios describe a future world of rapid economic growth, low population growth and fast incorporation of new and more efficient technologies.

Branch A2 represents scenarios for a very heterogeneous world; the bases are the self-development and the preservation of the regional identity, with high population growth. Economic development is guided, predominantly, by the regionalism and the economic growth per capita. Technological changes are slow and more fragmented that in the other branches.

Branch B1 and its family of scenarios describes a convergent world with the same low population growth as in branch A1 but with fast changes in the economical structures in the direction of services and information, with reduction in the intensity of raw matter demand and with the introduction of clean and efficient technologies. The emphasis is in global solutions for the economy, social and environmental challenges including increase in the social justness but without additional initiatives in the climate.

Branch B2 and their scenarios describe a world in which the emphasis is on local solutions for the economical, social and environmental challenges. It is a world of moderate population growth, intermediate levels of economic development and a slower and a more diversified technological change. While oriented for the environmental protection and the social justness, that branch focuses on local and regional levels.

2.2 The nuclear contribution

The International Atomic Energy Agency (IAEA) coordinates an international project to assess the potential of nuclear energy within those scenarios, with the aim of contributing to the development of global strategies, clarifying possibilities and defining requirements. In this project, named INPRO – International Project on Innovative Nuclear Reactors and Fuel Cycles, the scenarios are analysed delineating the necessary nuclear transition for each one [3]. Figs. 3 and 4, respectively, show the projection of the electric and nuclear energy productions in accordance with SRES data. One can see, from all of those scenarios, that the substantial expected growth of energy production necessitates an increase in the use of nuclear energy for the next 100 years.

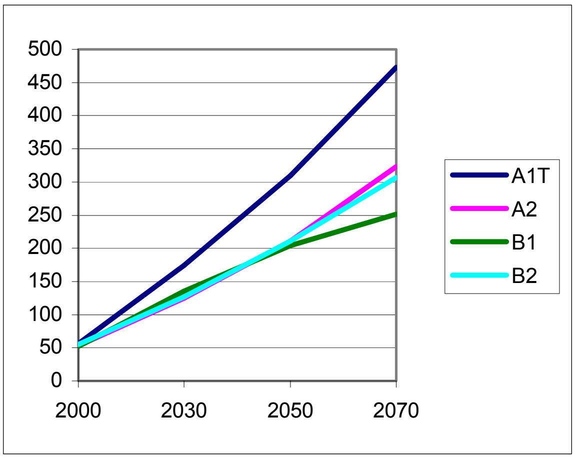

Figure 3. World production of electric power for each scenario.

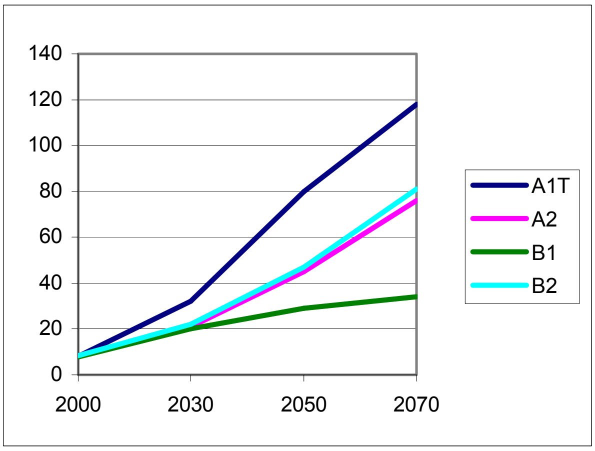

Figure 4. World production of electric power due to nuclear sources for each scenario

IAEA analyses the SRES scenarios in the following way:

Branch A1

- The main product is the electricity but there is also a significant market in the production of hydrogen, especially after 2030;
- Starting from 2030 the increase in capacity is larger in Asia and in a large part of Africa, Middle East and Latin America;
- The growth in the demand of hydrogen is initially dominated by OECD, and around 2050 moves to Asia and a large part of Africa, Middle East and Latin America;
- The initial competition is balanced among coal, gas, nuclear and solar. The coal share decreases starting from 2020, while the share of gas starts decreasing from 2040, leaving the competition between nuclear and solar;
- In the countries of OECD and of the European East, there is the supposition that nuclear energy loses the dominance for the solar, hydraulics and wind energies between 2050-2060.

Branch A2

- The market product in this case is, exclusively, the electricity. There is no production of hydrogen for nuclear reactors;
- Before 2030, the increases in capacity are larger in the countries of OECD, followed by Asia, Africa, Middle East and Latin America. After 2030 those areas continue to dominate the demand of capacity increments, mainly in the countries that have few reserves of competitive fuel sources;
- Up to 2030, coal followed by gas, will be the main competitors of nuclear. After 2030 the solar option will take on this role;
- In the countries of OECD and of the European east, coal is dominant up to 2050-60;
- The performance of nuclear will be lightly superior to the solar in OECD while the solar should assume a more important role in Asia starting from 2030.

Branch B1

- In these scenarios, the global and regional use of energy reaches a pick among 2060-80 and then it decreases;
- The change of the increase in the demand from countries of OECD to those in development becomes faster;
- The main market products are electricity and hydrogen, with the latter starting to be significant from 2030 on;
- For those products the main increases in capacity will be in Asia, Africa, Middle East and Latin America, then in OECD and finally in East Europe;
- After 2030, the main market is not in Asia, Africa, Middle East and Latin America;
- Up to 2040 the main competitors of nuclear for electricity will be solar energy and gas;
- After 2040, for the production of hydrogen, the competition will be in the following order: gas, biomass and solar;
- It is assumed that solar overcomes nuclear for the generation of electricity and production of hydrogen at the end of the scenario view.

Branch B2

- The growth of the nuclear energy varies regionally and, about 2050, is higher in Asia;
- In the period of 2040-50 the developing countries have a great growth in the nuclear energy;
- The electricity continues being the main product of the nuclear power plants.

In most of the scenarios, there are good possibilities for the nuclear energy, mainly in countries like Brazil that has the sixth largest reserve of uranium in the world. The additions of energy offered by nuclear sources will still grow, even in the worst scenarios, at least up to 2040-2050 (Fig. 5), thus providing better market opportunities for reactors like IRIS (targeting deployment in ~10 years) than for Generation IV reactors (targeting deployment in the 2030 timeframe).

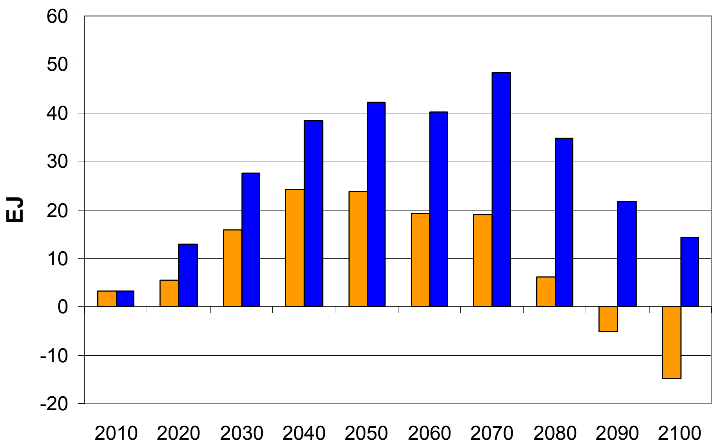

Figure 5. Increments in the world production of electric power due to nuclear sources for the two extreme scenarios (maximum growth in blue, minimum growth in orange)

There is a new market in the Northeast Region of Brazil, small in world terms if compared to electricity and hydrogen, however significant in areas with water shortage: *the desalination*.

2.3 Water: *Challenges for life and welfare*

The challenges for the life dependence on water involve not just the management of its use and demand. The signs of tension are apparent all over the world, mainly for the attainment of basic needs, protection of ecosystems, supply of water in large cities, supply of food, and water for industry and energy. With the continuous growth of the population and of pollution, the pressures tend to grow still more.

According to the "World Water Assessment Programme" of UNESCO, "to have safe access to enough water and basic sanitation is a basic human right. To have the possibility to wash the hands and to drink clean water can produce a large effect in the hygiene and family health, avoiding diseases that perpetuate the poverty and maintains a vicious cycle that blocks the social and economical development" (http://www.unesco.org/water/wwap/index.shtml).

To assure basic needs, 20 to 50 litres of water free from pollutants per person a day are necessary. The availability of water for a child in the developed countries is 30 to 50 times larger than in the developing countries. The United Nations (UN) established the goal of reducing by 50% before year 2015 the portion of people without access to the drinking water. It is estimated that 1.1 billion of people do not have access to an adequate amount of good water in the world, 6% in the Latin America. (Executive Summary of the WWDR.WHO/UNICEF Joint Monitoring Programme, 2002. updated in September of 2002.)

2.4 Desalination and the DEEP Code

Desalination of water on wide scale involves two technological areas: the generation and conversion of energy, and the desalination processes itself. Regarding desalination itself, basically three processes and their combination represent the state of the art: Multiple Effect Distillation [MED] expansion in multiple apprenticeships, Multi-Stage Flash [MSF]); Membranes – Reverse Osmosis [RO]; and, Hybrid ([MED/RO] or [MSF/RO]).

The present project will consider the hybrid process [MED/RO] with both types of energy conversion, electric or thermal, from two different sources: natural gas and nuclear (IRIS Reactor). The economic evaluation and comparison of the alternatives will be performed using the IAEA DEEP code.[4] The system will be analysed considering the delivering of desalinated water and/or net saleable electric power.

DEEP is the acronym for "Desalination Economic Evaluation Program" and is an evolution of the "Co-generation and Desalination Economic Evaluation" Spreadsheet, CDEE, that was developed by General Atomics, under contract, to the International Atomic Energy Agency, IAEA. The new user-friendly version has been issued under the name of DEEP at the end of 1998.

DEEP is based on the spreadsheet methodology, making use of MS ExcelTM. The Spreadsheet Methodology for Co-generation/Desalination Economic Evaluation is suitable for economic evaluations and screening analyses of various desalination and energy source options for several reasons. Today, the use of spreadsheets is a commonly adopted way to cope with engineering and scientific calculations. In the case of DEEP, these calculations include simplified models of several types of nuclear and fossil power plants, nuclear and fossil heat sources, and both distillation and membrane desalination plants.

Current cost and performance are incorporated into the code so that the spreadsheet can be adapted to analyze a large variety of options with very little new input data required. The spreadsheet output includes the cost of water and power, breakdowns of cost components, energy consumption and net saleable power for each selected option.

Specific power plants can be modeled by adjustment of input data including design power, power cycle parameters and costs. This is what will be done with respect to IRIS, a new design not included in the actual version of DEEP.

One important advantage of spreadsheet programs is that they are widespread and they run on every modern personal computer. For user interface, implementation of the VBA for Excel was used (VBA means Visual Basic for Applications and it is incorporated into the Excel environment). Excel is one of the spreadsheet programs most frequently used all over the world. Another advantage is the facility to store data and create tables and graphs.

DEEP allows the side-by-side comparison of a large number of design alternatives on a consistent basis with common assumptions. It also enables identification of the lowest cost options for providing specified quantities of desalinated water and/or power at a given location. It gives an approximate cost of desalinated water and power as a function of quantity and site specific parameters including temperatures and salinity. However, the spreadsheet is based on simplified models. The production costs achieved are approximated values, which should give a first indication to start a more thorough examination based on substantive information including project design and specific vendor data.

DEEP is prepared for quick evaluations with the plant types described in Table 3.

Table 3. Different Desalination Plants evaluated with DEEP.

3 RC	Energy source	Abbreviation	Description	Plant type
1	Nuclear	PWR	Pressurized light water reactor	Co-generation plant
2	Nuclear	PHWR	Pressurized heavy water reactor	Co-generation plant
3	Fossil – coal	SSBC	Superheated steam boiler	Co-generation plant
5	Fossil–oil/gas	SSBOG	Superheated steam boiler	Co-generation plant
6	Fossil	GT	Open cycle gas turbine	Co-generation plant
7	Fossil	CC	Combined cycle	Co-generation plant
8	Nuclear	HR	Heat reactor (steam or hot water)	Heat-only plant
9	Fossil	B	Boiler (steam or hot water)	Heat-only plant
10	Nuclear	GTMHR	Gas turbine modular helium reactor	Power plant
11	Fossil	D	Diesel Power plant	
12	Nuclear	SPWR	Small PWR	Co-generation plant

For each of above listed cases the performance and economic evaluation is made automatically for the four desalination technology combinations if applicable (Table 4).

Table 4. Different Processes within DEEP.

Process	Abbreviation	3.1 Description
Distillation	MED	Multi-Effect Distillation
	MSF	Multi-Stage Flash
Membrane	SA-RO	Stand-Alone Reverse Osmosis
	C-RO	Contiguous Reverse Osmosis
Hybrid	MED/RO	Multi-Effect Distillation with Reverse Osmosis
	MSF/RO	Multi-Stage Flash with Reverse Osmosis

Every desalination process requires energy. The heat energy required for distillation can be extracted from the steam cycle of a fossil fired or nuclear power plant, from a heating plant or from suitable waste heat sources. Electricity, which is required for all desalination processes, can be taken from a power plant or from the electrical grid. DEEP is designed to calculate these energy inputs and the water (and electricity, if applicable) production costs (Fig. 6).

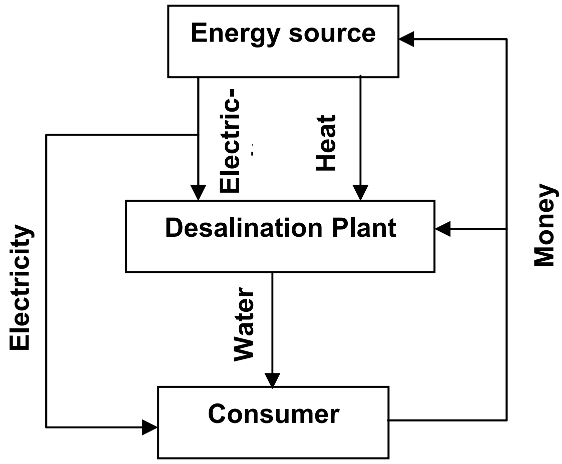

Figure 6. DEEP Balance Concept Diagram.

3.2 The Project for the Brazilian Northeast

Focus: The project intends to reach the entire semi-arid region, with the initial focus in the city of Recife (Fig. 7). The methodology is based on the assessment and analysis of social, economic and environmental data, from Recife to the extreme region of the Polygon of Drought, following lines of equivalent population. The process will define boundaries in accordance with the expansion capacity of each one of the options, natural gas and nuclear energy. In the case of nuclear power, the basis unit is one IRIS module of 335MW(e) (Fig. 8).

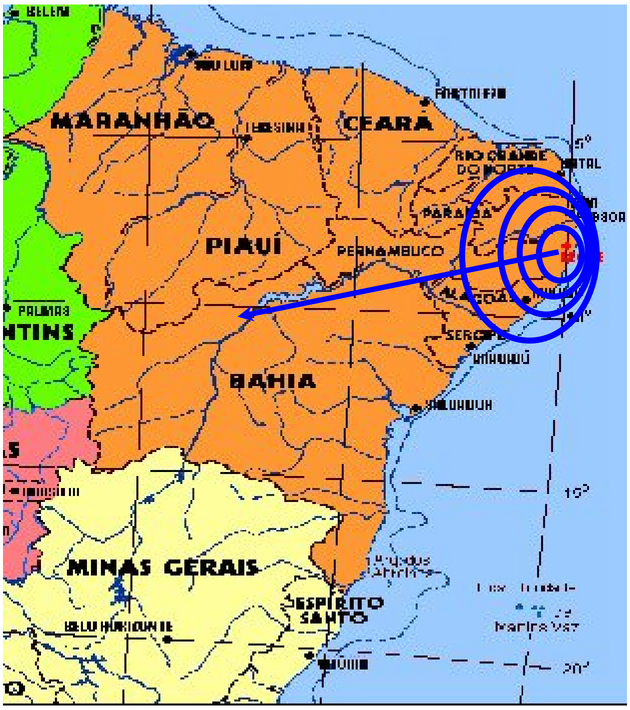

Figure 7. Initial focus of the Project within the Brazilian Northeast Region.

IRIS Reactor: IRIS is a modular, integral, light water cooled reactor, designed for a thermal power of 1000MW(t), with a net electrical output of about 335 MW(e)/module. The most relevant technical characteristics of IRIS are discussed in detail in references [5-7]. Its “safety by design” approach, where accidents are eliminated by design to the maximum extent possible, instead of engineering how to cope with their consequences is presented in [7,8].

The IRIS integral vessel houses the reactor core, its support structures, upper internals, control rod drives and drive mechanisms, eight steam generators, internal shields, pressurizer and heaters, and eight reactor coolant pumps (Fig.8). Hot coolant rising from the reactor core to the top of the vessel is pumped into the steam generators annulus. The integral vessel configuration is essential to the safety by design approach and thus it is key to satisfy the enhanced safety requirement.

The three most innovative features, which characterize IRIS project, are:
- Safety by design;
- Optimized, 48 months interval maintenance; and,
- Long core life.

These and other aspects, economy in particular, make IRIS an excellent option for building modular stations to deliver both energy and desalinated water. IRIS should be a cost-effective approach for regions without hydraulic and fossil options like the Polygon of Drought.

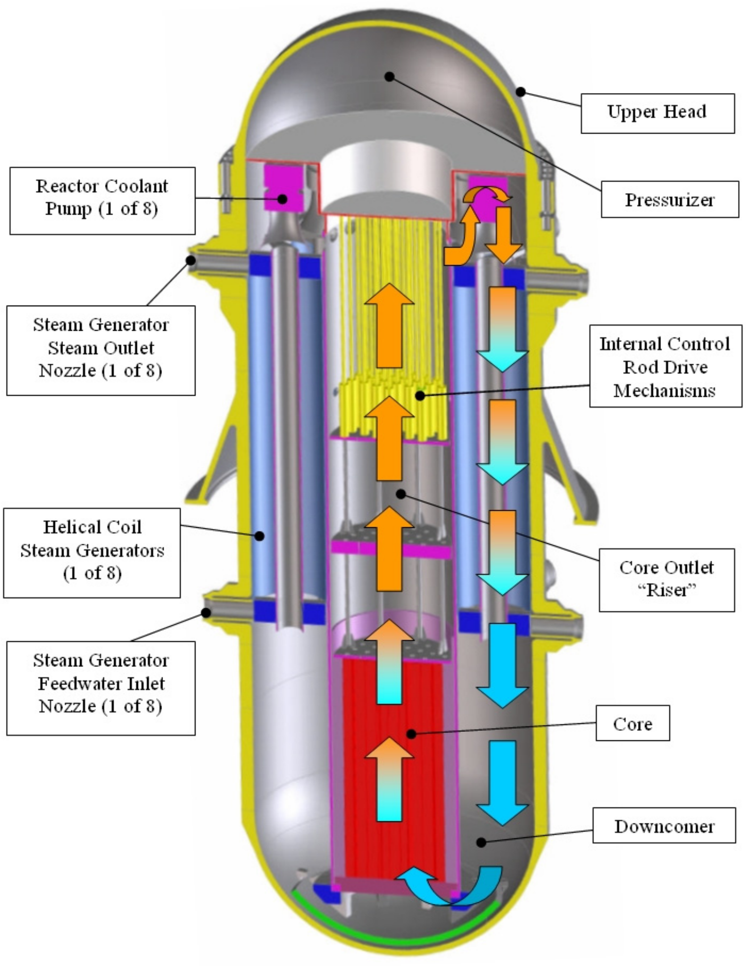

Figure 8. IRIS: Integrated Primary Systems.

Gas: Gas is a justified option because Petrobras operates a large gas pipeline in the Northeast (Fig. 9). Once again, the option is more attractive if focused in the Recife area.

Impacts: The methodology proposed for this project considers the assessment of economics for electricity production, desalination and distribution of water. The project will also quantify the external costs of energy production, the environmental impacts for the production of the water and energy, taking into account the development indicators and sustainability.

Figure 9. Northeast Gas Pipelines (existing shown in red, in construction shown in orange).

Since the early 1970´s, there has been interest in the environmental impacts caused by the generation of electricity. The comparative risk assessment studies at that time used mainly deaths and injuries as impact indicators. By the end of the 1980´s studies changed to the assessment of the costs imposed on society and the environment that were not included in the market price of the energy produced, the so-called external costs. The preliminary studies that were published set the conceptual basis, grounded in neo-classical economics, for the evaluation of the health and environmental impacts.

In view of the many questions raised by the methodologies employed by these early studies, the European Communities established a collaborative research programme to identify an appropriate methodology for this type of work. Following the completion of this collaboration, the programme has continued as the ExternE Project [9]. Since the year 2000 the Brazilian Nuclear Energy Agency has established a research programme to introduce the ExternE Project proposals into the main fuel cycles used in Brazil, defining the most important scenarios for their environmental and social cost.

The present work will compare the impact pathway methodology for the natural gas and the nuclear fuel cycles, without loosing the nuclear-specific techniques required for a proper evaluation, and the main environmental and social costs values of the desalination plant considering each fuel technology.

The impact pathway approach will require an inventory and assessment of all potential impacts; however, within the context of the ExternE methodology it will be not possible to consider all of them. Therefore, only the most important impacts, called priority impacts, will be included.

With regard to the nuclear cycle, the hypothetical releases of radioactive material to the environment, which could potentially affect public health, will be given the highest priority. However, the probability for such events has been significantly reduced in IRIS due to its safety-by-design and safety approach in general. Occupational health impacts, from both radiological and non-radiological causes, will be the next priority, even though the extent to which occupational health impacts can be considered as externalities has not been addressed.

In the natural gas cycles, the highest priorities will be the effects of atmospheric pollution on human health, occupational and public accidents, and the next priorities will be effects of atmospheric pollution on crops, forests and global warming potential of greenhouse gas emissions.

4 CONCLUSION

Any project for a social, economic and environmental assessment of the use of an advanced nuclear reactor for electric power generation and production of consumption water requires, besides a detailed report with technical, social and environmental information, a careful planning taking in account the need for precise estimations. This is what will allow a correct comparison of available energy alternatives. For those assessments, besides precise data, we need to develop and use novel techniques and appropriate tools.

Important steps were accomplished. The first one was the delineation of the project to create a development pole starting of the city of Recife. This stage enabled us to establish a cooperative program between the Energetic and Nuclear Research Institute, the Federal University of Pernambuco and the Regional Centre for Nuclear Sciences at Pernambuco. This cooperative program got financial aid from the Fund of Energy of the Brazilian National Council for Research and Development (CNPq).

Another important step was the collection of social and economic data of the Northeast Region to be mined with appropriated tools.

Two important tools were obtained. The first of them was the authorization from the International Atomic Energy Agency for the use of the DEEP code; the other tool, the ArcView code, was acquired with internal resources. ArcView is necessary for the consolidation of the data in the form of maps. The tools for the evaluation of the environmental impact in terms of external costs of the energy and of the residues of the desalination will be developed

5 ACKNOWLEDGEMENTS

The authors would like to thank the Brazilian National Council for Research and Development (CNPq)) of the Brazilian Ministry of Science and Technology (MCT), for its financial support.

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