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STUDY OF THE ENVIRONMENTAL COSTS TO NUCLEAR POWER PLANTS USING THE PROGRAM SIMPACTS

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ABSTRACT

The nuclear energy presents advantages in comparison with other kinds of energy sources, when their externalities are evaluated. Externality is a term that represents the side effects of production of goods or services on other people not directly involved in the activity. The externalities can be identified and related to the term environmental cost. The environmental cost is a externality that somehow affects the environment, converted into economic terms, to then be compared with other costs of an action or enterprise. The environmental cost can be calculated through programs for that purpose, however for the nuclear area is the most used SIMPACTS, developed by the International Atomic Energy Agency (IAEA). The motivation for this work arose from the need to have a complete assessment of environmental costs from nuclear power reactors, although it is known that this kind of form of energy generation show an advantage over others with regard to externalities. This work is the first step in implementing the program SIMPACTS in plant Angra 2 in order to calculate the environmental cost of their operation. The objective is to develop a methodology for calculating environmental cost for nuclear power reactors. SIMPACTS program will be used to identify the advantages and disadvantages of a cost analysis of environmental and perform the calculation of environmental costs for Angra 2, with the aim of minimizing the environmental impacts of its operation. From an extensive literature search, is presented in this paper the methodology for calculating the environmental cost of the program SIMPACTS and some results of calculations with the environmental cost in international power reactors other power generation plants.

1. INTRODUCTION

The most of the energy generated in the world comes from fossil fuels. The energy model in most countries is based on fossil fuels consumption, like oil, natural gas and coal. The main problem with this model is that the resources are not renewable, and thus their use is limited to long, medium or even short term. In addition, fossil fuels cause much damage to the environment, can be noted that air pollution directly affects the health of people and their lives.

Alternative sources of energy appear as an option, by use of renewable raw materials for energy production. They do not emit greenhouse gases, and by using renewable raw materials and abundant, contribute to ensure sustainability desired, especially by developing countries [1].

The main alternative sources of energy are wind, solar and biomass. Among the alternative sources, is nuclear energy, which is standing out among the others, especially in Brazil, with

the operation of nuclear power plants Angra 1 and 2, in Angra dos Reis, and more recently with the construction of Angra 3 [2].
The objectives of this paper are an extensive literature search, present the methodology for calculating the environmental cost of the program SIMPACTS and present some results of calculations with the environmental cost in international power reactors and other power generation plants.

In recent years, the nuclear option for electricity generation has grown as the environmental objections decreased. The main reason for this is based on the perception that the issue of waste generated reaches not only nuclear energy but also the entire set of thermal energy, where nuclear power is included, while the others still have the issue of aggravating greenhouse gas emissions [3].

2. ENVIRONMENTAL COST

2.1 Externalities

Alternative sources of energy, including nuclear, have advantages with respect to externalities. Externality is a term that represents the several effects of production of goods or services to people are not directly involved with the activity [4]. Externalities can be positive or negative, it general costs or benefits to society. Regarding the use of fossil fuels, pollution generated by them affects external agents that do not necessarily share the benefits, only harm.

2.2 Environmental cost

The externalities can be identified and related with the term: environmental cost. The environmental cost is an externality that somehow affects the environment, converted into economic terms, so it can be compared with other costs of an action and / or enterprise [5].

For a complete assessment of the costs, damages and external costs should be quantified first and then integrated into the decision-making process. In most cases, estimated damage is a major challenge, due to the limits of current knowledge on the subject, and because of large amounts of data needed to perform the analysis. For these calculations there are some specific programs that enable the conversion of the damage in economic terms and the inclusion of environmental costs in the cost analysis of a specific project.

2.3 Calculation programs

In the literature are found some programs to calculate of environmental costs, for different energy sources, such as the ExternE [6], the Decades (Databases and Methodologies for Comparative Assessment of different Energy Sources for Electricity Generation) [7] and B-Glad [8].
Another program developed by the IAEA to calculate the environmental cost of nuclear power plants is SIMPACTS (Simplified Approach of Estimating Impacts of Electricity Generation) [9], which is the object of this study and following described.

2.3.1 SIMPACTS

SIMPACTS is a program that estimates and quantifies health and environmental damage costs, called externalities, of different electricity generation technologies. This tool particularly useful for comparative analyses of the: fossil, nuclear and renewable energy. In case of the new power plants are expected better environmental mitigation policies [10].

The program SIMPACTS has a decision helper module, which allows a comparison of the relative merits of different technologies according to different criteria selected. The most significant aspect of the program is its simplicity and their users already deliver useful results when only limited data are available [10].

The model allows a user to make a range of external cost estimates ranging from crude to accurate, depending on available data. An approximate estimate can be obtained with input on average population, plant characteristics and emissions. Given the high uncertainties involved in any estimation of external costs, SIMPACTS produces results well within the range of more complex models [10], Fig. 1.

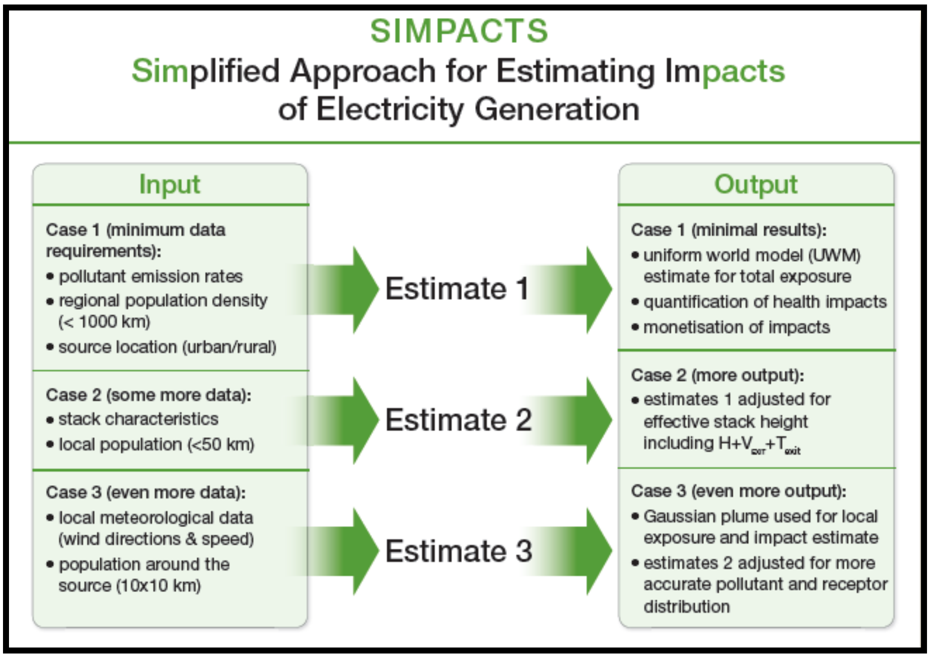

Figure 1. Input and output data of the SIMPACTS

The program consists of separate modules for estimating the impacts agricultural crops and buildings resulting from routine atmospheric emissions of pollutants from energy facilities. A decision aiding module permits comparison of the relative advantages of different technologies. This modules are: AIRPACTS to quantify the impacts and costs of damage caused by atmospheric emissions; NUKPACTS for collective doses evaluation and health effects of latent routine operation of nuclear installations and the external costs of accidents of deposition of waste; HYDROPACTS to calculate the costs of hydroelectric dams damage resulting from the relocation of people due to flooding and loss of land use; and DMA, an auxiliary model, allowing an analysis of political decision, taking into account different criteria [11] as diagram in Fig. 2.

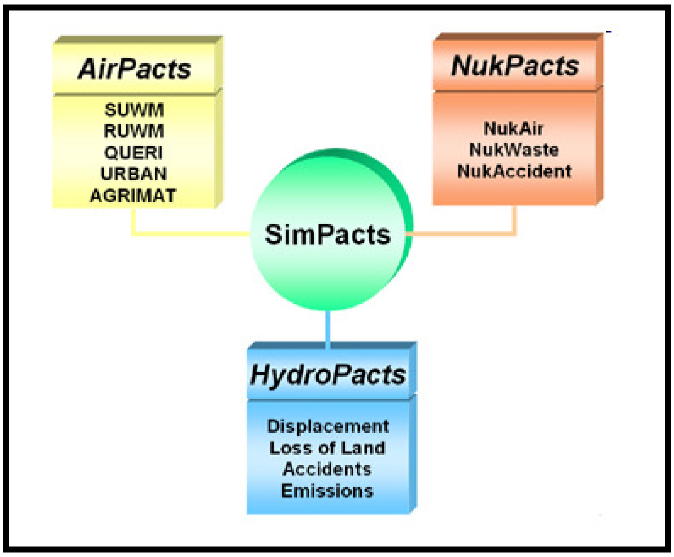

Figure 2. Flow Diagram of SIMPACTS program

Among modules are part of SIMPACTS; the most used is the AIRPACTS. This module includes several models that represent different analytical approach to solve the problem. They are: the Robust Uniform World Models (RUWM) Quick Estimation of Respiratory Health Impacts (QUERI) and Urban Models (URBAN) [12].

To exemplify, the input data in the RUWM module are: population density, rate of emission of pollutants in tons per year, risk groups, the rate of decomposition of contaminants in the atmosphere and cost impacts in the United States, in the absence of specific data [12].

The URBAN model estimates the impacts and costs in the health arising from the issuance of primary and secondary pollutants from a source located in an urban area or near it. Data on the local population can be specified with a resolution of 5 km x 5 km, and the starting point is a central source of emission and extending to 50 km around it. Its distribution is calculated using a Gaussian distribution and it is necessary to know the background density (ρ_{fondo}), the position of maximum value (X_{max}, Y_{max}), the standard deviation (σ_D), the peak of the distribution (ρ_{max}) and the density of people the X and Y calculated according to the equation (1):

$$\rho = (\rho_{max} - \rho_{fondo}) e^{\left\{ -\frac{\left[(X - X_{max})^2 + (Y - Y_{max})^2 \right]}{2\sigma_D^2} \right\}} + \rho_{fondo} \quad (1)$$

Another module of the program is HYDROPACTS, it was developed to estimate some of the impacts and to quantify its costs. The model allows the calculation of the number of people displaced, the emission of polluting gases during the construction and operation of a hydroelectric and the impacts of accidents (lost lives and years of life lost due to disability) [12].

The HIDROPACTS allows valuing the social costs mainly due [12]:

1. Forced displacement of population;
2. Loss of land;
3. Loss of agricultural production;
4. Loss of natural and cultural resources;
5. Accident or failure in the dike;
6. Increased number of diseases;
7. Emissions of greenhouse gases and toxic gases in general.

The main SIMPACTS module for the development of this work is the NUKPACTS, which converts the impacts of the radioactive releases in normal operation and accidental of the nuclear power plant in monetary terms, as described in detail below.

The first step of calculation takes into account the source term, i.e., the dispersion of radionuclides in the atmosphere from the normal or abnormal operation of nuclear reactors. Table 1 shows an example, of the radionuclides released into the air and their half-lives to a reactor of PWR type, like Angra 2 [13].

TABLE 1. Main radionuclides released to the environment and their respective half-lives

Radionuclides	Half-lives	Radionuclides	Half-lives
Kr – 85	10.7 a	I – 134	52.6 min
Kr – 87	76.3 min	I – 135	6.6 h
Kr – 88	2.8 h	Cs – 134	2.1 a
Xe – 133	5.2 d	Cs – 136	13.1 d
Xe – 135	9.2 h	Cs – 137	30 a
Xe – 138	14 min	Co – 58	71 d
I – 131	8.1 d	Co – 60	5.3 a
I – 132	2.3 h	C – 14	5710 a
I – 133	21 h	H – 3	13.3 a

The second stage of calculation considers the transport and dispersion of radionuclides. The calculation of the annual average concentration of radiation per unit volume (Bq/m3) is performed using the model of Gaussian plume dispersion [14]. The data needed for this calculation are: the released power of each radionuclide, the annual average wind speed, the effective time of the release of the radionuclide and the corresponding category of stability according to the model of "Gifford-Pasquil" [13.15].

Equation (2) provides the relationship between wind speed and height of release:

Wind speed (the time of radiation released) = $V_k \times \left(\frac{h_k}{h_r} \right)^p$ (2)

Where:
V_k = wind speed at known height (m/s);
h_k = known height (m);
h_r = released height (m);
p = exponent which varies with atmospheric stability.

Atmospheric stability is calculated from Table 2.

TABLE 2. Example of the calculation of the coefficient of stability of the atmosphere

Stability de Class	Coefficient	Wind speed to 10m	Climate
A - very unstable	0,15	1 a 2.5	Very sunny
B – moderately unstable	0,15	1 a 5	Sunny
C slightly unstable	0,20	2 a 6	Part of cloudy day
D – neutral	0,25	2 a > 10	Cloudy
E - stable	0,40	2 a 5	Part of cloudy night
F – very stable	0,60	2 a 3	Clear night

The third step calculates the deposition of radionuclides according to equation (3) [15].

$$W_i = C_i \times V_d \quad (3)$$

Where:
W_i = average flow of the radionuclide ($Bq/m^2.s$);
C_i = annual average concentration of radionuclide in the air per unit volume (Bq/m^3);
V_d = average speed of deposition (m/s)

The fourth step treats of the exposure of the general public to radionuclides, and considers the following aspects [15]:

1. Inhalation of radionuclides in the air;
2. External irradiation of the cloud;
3. External irradiation of the deposition on the ground;
4. Ingestion of radionuclides in food.

Each of these forms of exposure is calculated by means of mathematical equations that can be easily found in the literature [15].

The fifth step, corresponding to the expected impacts on human health, consider the fatal cancer caused by radiation that can occur in the population, cases non-fatal of cancer and the cases of severe effects of the radiation on future generations of exposed populations [15].

The sixth and final stage performs the conversion of the impacts identified in monetary terms (monetary valuation). The model has the economic values data of the impact of radiation on the health of the population of many countries; however, the program user can enter their own values previously calculated. This information should be provided in monetary units ($, €, etc.) and standard units of currency for energy ($ / kWh, € / kWh, etc.). [15].

With these modules, SIMPACTS covers the major energy sources and most of the associated impacts on human health and the environment. The most important, it provides a simple but accurate tool for estimating external costs associated with electricity generation. The model can be used for comparing and ranking various options in terms of these external costs [11].

Following are presented some example of the use of the SIMPACTS program.

3. EXAMPLES

In the literature are found some data from SIMPACTS results to nuclear reactor in France. The data obtained are of the occurrence of a sever accident, whose risk is around 1.9E-6. The following parameters are calculated from this data: the number of deaths (3,000), number of cases of non-fatal cancer (9,000) and individuals relocated (10,000). The sum of all costs for this French utility, converted into monetary values, was around 18 billion dollars. In addition, the damage expected in terms of levels of radiation for this French plant, which produces 7.6 TWh, it is around 0.0044 mills/kWh [16].

Another example of SIMPACTS implementation is to evaluate damage cost produced by electrical power plants. A study made an assessment of externalities from electric power plants on Mexico City Metropolitan Area. An original method was developing to use de impact pathway approach of SIMPACTS to estimate the damage costs in this case. The estimate shows that the annual costs total 71 millions USD [17].

Similar study was conducted for damage costs of Syrian electricity generation, using the impact pathway approach. The obtained results indicated that the environmental impacts could add considerable external costs to the typical generation cost, of which externalities vary between 2.5 and 0.07 USD-cents per generated kWh [18].
All studies emphasize the importance of quantifying power generation externalities and to minimize environmental impacts.

4. CONCLUSION

In this paper was presented the methodology for calculating the environmental cost showed in the program SIMPACTS and environmental cost calculation to the France reactor and other power generation plants. However, in the future will be calculated the environmental cost to Angra 2, using the proposal methodology, which is of the objective of the master degree of the student Francine Menzel.

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