2009 International Nuclear Atlantic Conference - INAC 2009
Rio de Janeiro,RJ, Brazil, September27 to October 2, 2009
ASSOCIAÇÃO BRASILEIRA DE ENERGIA NUCLEAR - ABEN
ISBN: 978-85-99141-03-8

ENVIRONMENTAL MONITORING PROGRAM OF A NUCLEAR RESEARCH INSTITUTE

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ABSTRACT

The main activities of the CDTN Research Institute are concentrated in the areas of reactors, materials, process engineering, the environment, health, radioprotection, radioactive waste, and applied physics. Its Environmental Monitoring Program (EMP) began in 1985 with the objective of evaluating and controlling its installations' operating conditions as well as the impact on the neighboring environment caused by release of stable and radioactive elements. EMP's adequate planning and management resulted in obtaining an unique database that has generated information which have contributed to improving the credibility of nuclear and non-nuclear activities developed by the Center with the local community. Besides this, the data collection, study and continuous and systematic follow-up processes of environmental variables allowed the Center to be one of the Nation's pioneering research institutions in obtaining an Environmental Operating License from the Brazilian Environment and Natural Resources Institute (IBAMA). The objective of the present work is to present the experience acquired during the years, including a discussion about methodologies employed as well as the importance of using statistical evaluation tools in evaluating, interpreting, and controlling the quality of the results. Liquid effluent control and surface water monitoring results are also presented.

1. INTRODUCTION

In Brazil, Environmental Impact Analysis (EIA) involves a known set of environmental management methods and techniques for the purpose of identifying, predicting and interpreting environmental effects and impacts from proposed actions, such as: soil legislation, policies, plans, programs, and activities, among others. This study deals with various technical activities, among them: (a) environmental diagnostics, (b) prognosis of environmental conditions with the execution of the project, (c) mitigating and potentializing environmental measures to be adopted, and (d) the environmental follow up and monitoring program.

An environmental monitoring program (EMP) can be defined as a data collection, study and continuous and systematic follow up process of environmental variables seeking to qualitatively and quantitatively identify and evaluate the conditions of natural resources at a specified moment as well as the tendency over time (seasonal variations) [1]. EMP results are used to aid in planning measures, control, recovery, preservation, and conservation of the studied environment, as well as help to define environmental policies. Implementation of an environmental monitoring program involves a lot of effort to allocate human and financial resources.

Regulatory Position 3.01/008 "Environmental Radiological Monitoring Program" from the Brazilian Nuclear Energy Commission [2] establishes the main requirements for development of an operational EMP for radioactive and nuclear installations. According to this Regulatory Position, the following items should be dealt with:

- definition of indicators/parameters to be evaluated, matrices (air, water, and soil) to be monitored, sampling or collection points and frequency of data gathering;
- description of the analysis methodologies; sample collection, preservation, storage and transportation procedures (to the Analytical Laboratory);
- statistical evaluation and data registry methodologies;
- information processing and storage;
- communication of results.

A monitoring network is a planned and organized system for collecting specific and interrelated information that in turn generates information from the collected data and increases knowledge for decision making and environmental planning. The planning or design process of a monitoring network should take several aspects into account, among them [3]:

- the objectives to be attained in terms of information, uses and data users, not just at the moment of planning, but also in future use;
- in which area or region information should be collected;
- establishment of a data quality control program to generate greater credibility in the appraisals and reports emitted.

Quality control of the results emitted goes through the control of technician performance, collection methods and physico-chemical and biological analyses of different matrices, just as through application of statistical techniques to evaluate and interpret the data obtained. Both require the implementation of evaluation procedures that allow the control of possible variations that exist within the monitoring system as a whole.

Results for the different physical, chemical, and biological parameters selected for analysis inevitably vary as a result of variations that occur due to various factors that make up the process. The variability caused by common causes, known also as natural variability, is inherent to the process considered and will be present even if all of the operations are carried out employing standardized methods. When only these common causes are acting, variability is maintained in a stable range known as the characteristic range of the process [4]. Special causes of variation happen sporadically mainly due to the occurrence of a specific situation, such as contamination of a sample, which makes the process behave completely differently than it usually does.

The objective of the present work is to show EMP evaluation and follow up methodologies, emphasizing the importance of the use of statistical tools in interpretation and quality control of Environmental Monitoring Program (EMP) results. In order to give an example of the collection, analysis and data processing methodologies, a case study is presented in which procedures adopted by the Nuclear Technology Development Center (CDTN) are described. CDTN is a research institute linked to the Brazilian Nuclear Energy Commission, located beside the 240 000 m^2 Ecological Park of the Minas Gerais Federal University (UFMG).

2. STATISTICAL DATA PROCESSING

Statistical data processing involves not only estimation of the description parameters, such as average, mode, median, standard deviation, variance, etc., but also application of statistical techniques that allow detection of deviations in the process and probable causes to be determined in order to orient the action to be taken; identification of discrepant values and study of seasonal tendencies. The following described techniques were employed in this study.

2.1. Control Charts or Graphs

Statistical control graphs are graphic tools that use sequential sampling to reveal when the process alters and requires corrective action. Beyond offering visual exposure of the project's representative data, the main focus of the control graph is to try to separate special or identifiable causes of variation from common or chance causes [5].

For example, the control graph for average concentration values of specific chemical elements in different environmental matrices (water, air, and soil) in function of sample frequency allows tendencies caused by alterations in the process to be detected, such as a change in the analytical method, alterations in sampling procedures, etc. Points outside of the control limits require an investigation of the cause of the responsible variation for their occurrence.

2.2. *Box Plot* Graphs

Box plot graphs allow the main differences between monitoring results at different sample points to be better visualized. These graphs simultaneously present various characteristics of a data set: location, dispersion, symmetry or asymmetry, and presence of outliers, allowing comparisons of the monitored data sets to be made independent of distribution form. In addition, the *box plot* is built based on the median and the quarters associated with data collection, which makes the *plots* resistant to disturbing values within the barrier of *ouliers* and consequently attractive in exploratory data analysis [6]. An *outlier* or discrepant point is a value located away from almost all other distribution points.

2.3. Dispersion Graph

The line or dispersion graph is one of the most important graphs: it represents observations made over time at equal or unequal intervals. Such data sets make up so-called *historical series* or *seasonal series*. They translate a phenomenon's behavior in a certain time interval.

When analytical results have been acquired, line/bar graphs can be drawn for each collection point, sample type and analysis performed, which will indicate the increment of, for example, concentration in the system as a whole. From the increment history, a specific line graph can be generated for each sample point, type and analysis. On it, the current situation can be verified and possible seasonal trends can be analyzed [4].

3. CDTN ENVIRONMENTAL MONITORING PROGRAM

3.1. General Considerations

Liquid effluents, radioactive and non-radioactive waste are generated by the activities carried out by CDTN's various sectors. These in turn are a potential source of environmental contamination that if not adequately monitored and controlled can cause direct and indirect risks to man and the environment.

When authorized, release of liquid effluents into the environment must be done in attendance of relevant environmental legislation, including the requirements made by regulating and auditing agencies, among them the Brazilian Nuclear Energy Commission [7], the State of Minas Gerais' Environmental Policy Council [8], and the National Environmental Policy Council [9] for non-radioactive contaminants.

CDTN's Environmental Monitoring Program (EMP) has been in operation since 1985 and establishes the nature of the samples to be collected, location of sampling points, the type of analysis to be carried out on each sample and sampling and analysis frequency. Its main objectives are [10]:

- verify the source isolation and runoff release control conditions stipulated;
- provide means to show the public that the source and effluent release are under control;
- evaluate the increments detected in radioactivity or radionuclide and stable element concentrations in relation to operational phase, control areas and levels measured in previous years;
- estimate the environmental impact and, if necessary, to propose and to implement a complementary monitoring program and take other corrected actions which will lead to the return of imposed operational conditions;

- evaluate the tendencies in relation to radioactivity level measurements or concentrations of radionuclides and stable elements in areas subjected to environmental impact from practices and those that are not influenced (control areas), which permits the contribution of the evaluated practice to be distinguished from other sources.

- demonstrate conformity with established operational levels;

- Supervise the region in order to identify modifications in parameters that indicate need to revise the program; and

- Maintain a continuous register of measurements carried out that allow follow up of processes and audit of practices.

Until 2001, CDTN's EMP included only collection of radionuclides in liquid effluent, aerosol, soil, vegetation, surface water, sediment, and groundwater [10]. Beginning in August 8th 2002, CDTN received IBAMA (Brazilian Environmental and Water Resource Institute) Environmental Operation License. This is turn was conceded with conditions, among which was the inclusion of monitoring of stable elements present in liquid effluents released from CDTN installations.

3.2. Methodology

Below are described the collection and analysis methodologies for determination of stable and radioactive element concentration and physico-chemical parameters for surface water and liquid effluent samples from CDTN installations.

3.2.1. Sample Collection and Preservation

The amount of sample to be collected is defined from the concentration value of the element that is to be determined, the detection limit value of the equipment used or minimum detectable concentration in the analytical procedure adopted, and the degree of uncertainty allowed in the final result. The liquid effluent and surface water sampling procedures are described below.

The liquid runoff sampling point is located at the gate of CDTN before the junction with the UFMG sewer system. Samples are continuously collected. After 15 days, a composite sample is sent to the laboratories for analysis.

CDTN's Environmental Monitoring Program established three permanent surface water monitoring points. The first is located before the CDTN's effluent discharge point. This is considered a "Blank" point, that is, is shows the inherent conditions of the waterway before CDTN's runoff enters. The second is located just after the effluent discharge point, however this stretch of the waterway has been covered and also receives runoff from UFMG's main labs (Chemistry, Biological Science, etc.), which makes it difficult to evaluate the real contribution of CDTN's liquid effluents in altering the characteristics of the water previous to discharges. The third sample point is located right after the junction with the Pampulha River, where the water may be used in some form by the population that lives on the banks of the river.

All of these points have been established by means of a survey of hydrological data and use and occupation of the region's soil. Samples are taken monthly and occur simultaneously at all three established sampling points. All sampling is done under the Water Sample Collection and Preservation Guide of the Companhia de Tecnologia de Saneamento Ambiental (CETESB) [11].

3.2.2. Chemical Analyses

Chemical analyses of liquid effluent and surface water samples include determination of concentration of total alpha and beta activity, concentration of the natural radioactive elements ^{40}K, ^{210}Pb, ^{226}Ra, ^{228}Ra, ^{238}U, and ^{232}Th, concentration of oil and grease, ammonia, barium, cadmium, copper, total chromium, hexavalent chromium, mercury, silver, and nickel, as well as physico-chemical parameters such as pH, temperature, and conductivity.

Analytical methods employed depend on the analyte and matrix. Metal concentration in effluent and surface water samples is determined by cold vapor atomic absorption spectrometry and inductively coupled plasma atomic emission spectrometry. Oil and grease concentration is determined by the hexane extraction method and ammonia through cation exchange column [10].

Radioactive element concentration is measured using several analytical methods, among them retarded neutron analysis (^{238}U), neutronic activation analysis (^{232}Th), gamma spectrometry (^{226}Ra and ^{226}Ra) and flame photometry (^{40}K). Total alpha and beta activity and ^{210}Pb concentration are determined by the radiometric method, employing a gas flow proportional counter. In addition to these analyses, gamma radiation is measured by means of thermoluminescent dosimeters (TLD) [10].

3.3.3. Control and evaluation of results by means of statistical tools

Next, CDTN's Environmental Monitoring Program (EMP) results are presented along with the evaluation, interpretation, and quality control process adopted. Also discussed are aspects related to applicability and importance of using statistical tools in analyzing environmental monitoring data.

Figure 1 shows a line graph of total alpha activity results and associated errors from a specified sampling period (02/2000 to 12/2007), which allows comparisons to be made between the average concentration value in the evaluation period with averages from earlier periods.

Figure 2 shows the total alpha activity concentration results in liquid effluent samples. It is important to restate that the mobile amplitude graph should be used along with the average graph since it is utilized to control variability in the process. These graphs have the following configuration [12]:

1. The first graph presented in each Figure 2 is called the Average Graph and is utilized to evaluate location and dispersion of results, consisting of:

    - an average line (x-bar), which consists of average estimated μ by means of all of the values found in the period;

- a pair of control limits which are represented as one line below (lower control limit LCL) and another line above (upper control limit UCL) of the average line, utilizing standard deviation referring to the estimated average;

- Total alpha concentration values plotted on the graph.

2. The second graph shown in Figure 2 is called the Mobile Amplitude Graph which is used to estimate variability in the process. On all of the graphs, the “x” axis represents the year in which the campaign was carried out. The “y” axis represents the average annual total alpha concentration. The mobile amplitude graph consists of:

    - an average line (R) that represents the estimated average of all of the amplitude values found for each sample in the period represented;

    - a pair of control limits which are represented by a line below (LCL) and a line above (UCL) the average line utilizing the standard deviation that refers to estimated average;

    - amplitude values (R), with R = (result of the sample from the previous period – result of the sample);

    - control limits are estimated for a confidence level of 95 %.

Data shown on Figure 1 present the total alpha activity results at a single surface water sample point by means of a dispersion graph. These data arise from occurrence of seasonalities that could have been caused by variations in intensity of activity in the installation during the period as well as eventual abnormalities (distance of the present result from the levels encountered previously, alteration of analytical uncertainty, etc.).

As has been previously stated, using dispersion graphs allows any alteration in the process as a whole to be followed, be it in the sampling procedures, analytical protocols or significant changes in concentration values. The results presented on Figure 2 indicate that the average values found for total alpha activity are always remaining at the same levels, that is, very near the average. The control graphs don’t only indicate that variability of results is found within the control limits, but also there is no occurrence of trends or periodicity.

Figures 3 and 4 presents *box-plot* graphs for mercury and ammonia analyses in sampling points located upstream and downstream of CDTN’s liquid effluent discharge. The surface water collection points are located upstream (Point 042) and downstream of CDTN’s liquid effluent discharge (Points 043, 049, and 060). Analysis of these graphs allows existence or lack thereof of liquid runoff contribution from CDTN installations to be verified in the concentration levels of monitored chemical elements (radioactive or not). This type of graph also makes it possible to evaluate dispersion of results found for each sample point.

As can be seen in Figure 3, there are no ammonia concentration values considered discrepant. In addition, it can be verified that the median of the control values obtained upstream (point 042) is practically equal to that obtained for points 043, 04,9 and 060 (downstream of discharge). Thus liquid effluents from CDTN don’t contribute to the concentration levels of the elements monitored. Note as well that 50% of the data is in the interquartilic interval (the interval within the rectangle), of which 25% is between the median line and the line of the first quarter and the other 25% are between the mediam line and the third quarter line. Each tail line and the most discrepant values have 25% of the remains of the distribution, therefore indicating that there is little data dispersion.

In relation to mercury concentration value data behavior, the distribution of upstream concentration values can be verified to have a median slightly above the downstream values, thereby indicating that liquid effluent liberated by CDTN doesn't make a contribution. In this case, significant data dispersion can be observed at each sample point. This in turn could be caused by sample reproducibility since surface water sample points of CDTN's EMP have well differentiated characteristics [10].

3. CONCLUSIONS

All of the phases of an Environmental Monitoring Program must be submitted to a Quality Guarantee Program in which all of the operational and management procedures must be established and documented and describe at least: a) structures involved and assignment of responsibilities; b) qualification, training, and refreshing training; c) sample collection, identification, conservation, and storage techniques; d) analytical determination methodologies; e) analytical quality control methodologies; f) statistical processing methodology for data and results evaluation; and g) results registry and archive procedures.

The present work emphasized the importance of using appropriate statistical tools to evaluate final results. As has been shown, data processing goes well beyond simple comparison with the limits established in pertinent legislation. The use of control graphs permits separation of special causes of variations from common or chance causes of variations. Line graphs or dispersion graphs in turn represent behavior of a phenomenon over a certain time interval. *Box-plot* graphs contribute to a better visualization of the main differences between monitoring results in different sampling areas.

CDTN's EMP has been operating since 1985 and up to the present, alterations in the environment surrounding its installations caused by activities developed by the Center have not been observed. Implementation of a quality guarantee program in all of the steps of EMP execution (from collection of environmental samples to registry and archiving of results) has contributed not just to an increase in reliability of obtained results but also for greater transparency in communication with the public.

Finally, it's worth restating that EMP development and execution, as has been established by regulatory agencies, definitively contributed to making CDTN the only Brazilian nuclear research institutes to obtain an Environmental Operating License from IBAMA, conceded in 2002, and renewed for a six year period starting in 2006.

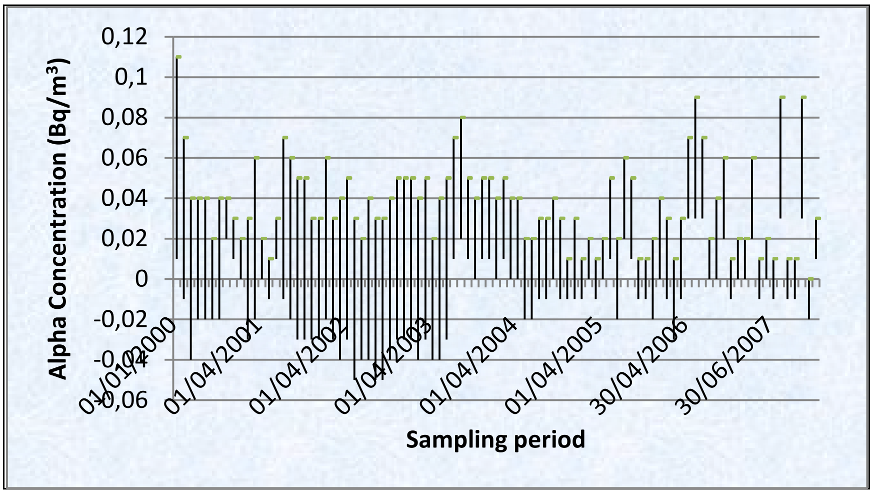

Figure 1. Total Alpha results in surface water samples.

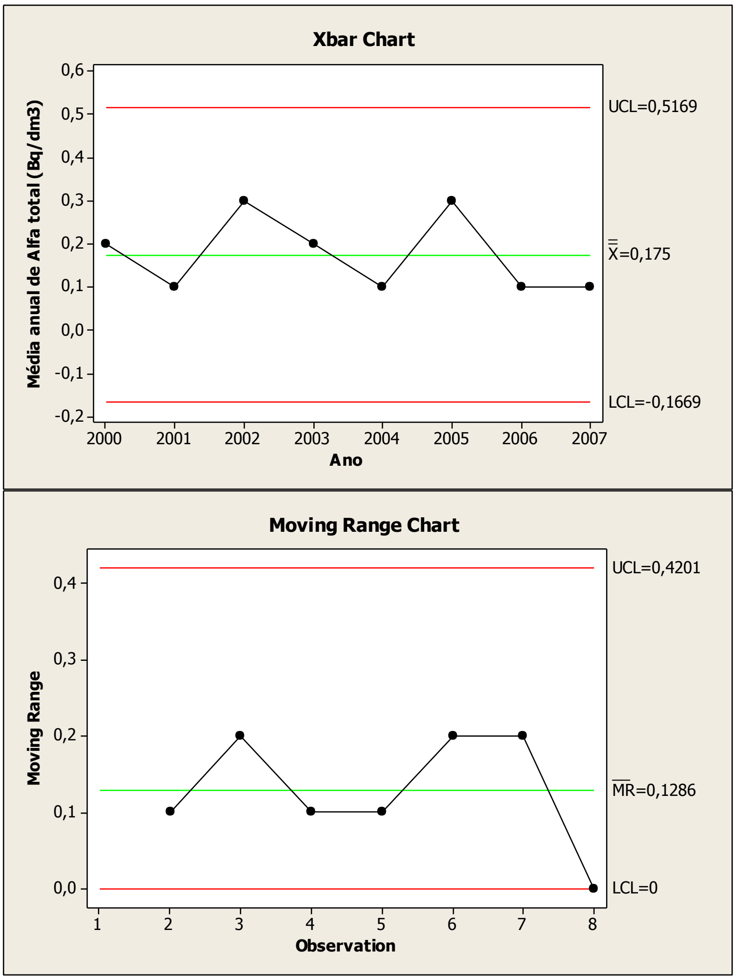

Figure 2. Control graphs for total alpha concentration results in liquid runoff samples

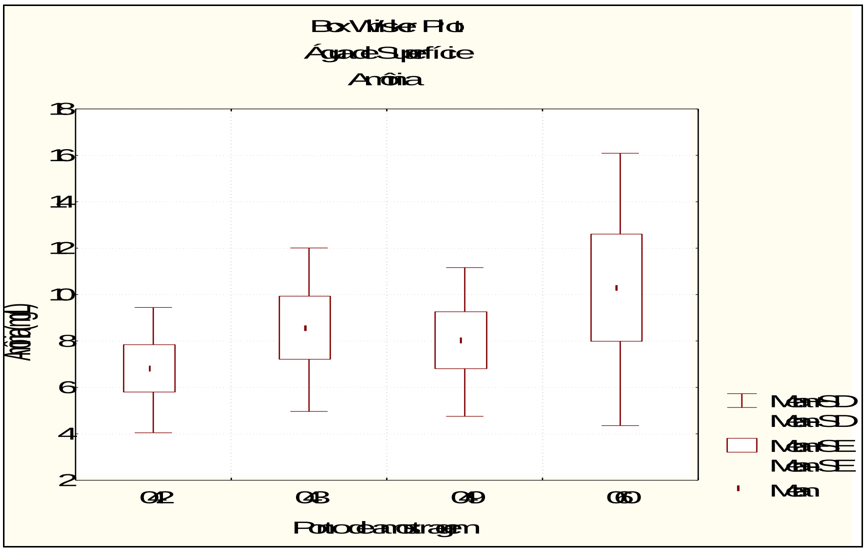

Figure 3. *Box-plot* graph for ammonia analysis in surface water samples**.**

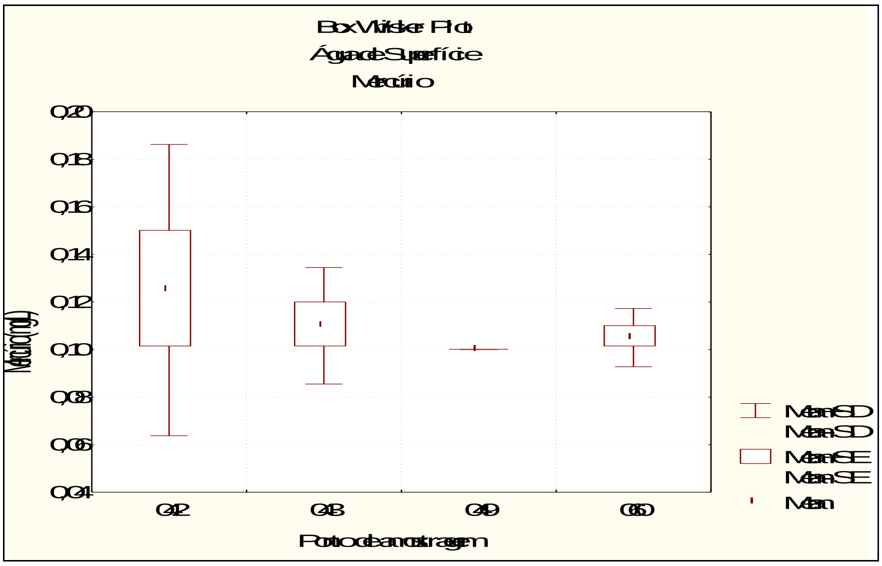

Figure 4. *Box-plot* graph for Mercury analysis in surface water samples

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