The experience of CDTN/CNEN, Centro de Desenvolvimento da Tecnologia Nuclear: A medium size nuclear research centre in Brazil

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Abstract. At first a university research centre, then a captive research centre of the state owned company in charge of establishing a nuclear industry in Brazil, then a research centre of CNEN (the Brazilian Nuclear Energy Authority), nearing its 50th anniversary, CDTN has a rich experience. even keeping the project portfolio around a number of traditional nuclear energy areas such as nuclear reactors, materials, environment, process engineering, waste management, radiological protection, the institution experienced an evolution in the substance of the proposed projects. This evolution represents the different institutional insertions, but the major changes occurred at a time when, due to a lesser demand from the nuclear sector and other factors, the explicit idea of producing outputs for the benefit of society received a large acceptance from the employees. The challenges to the institution at this time are commented upon. Retirements, coupled to the lack of job openings, work together for the decrease in the staff number, one major challenge. Up to a certain point, private companies have been hired to fill some of the organisational needs, but it is felt that a limit to this policy is being reached. It is argued that, even in the absence of a strong demand from the energy generation sector, a number of opportunities are still available to a NRC in a developing country. maturity of nuclear energy and applications of radiation tend to transfer the focus of the activities from the fundamentals of nuclear science and technology to quality related issues, a requirement of the modern times. quality systems cannot substitute for the in depth knowledge of the fundamentals.

Past and present situation of CDTN/CNEN

CDTN was founded in 1952 at the University of Minas Gerais, the result of the vision of a few persons. At that time, the presence of large amounts of uranium minerals in the State of Minas Gerais was taken for granted, given the existence of already known large Thorium ad Uranium deposits as well as many other minerals. Hence the name of the new Research Centre, Instituto de Pesquisas Radioativas.

During the sixties, CDTN remained as a small institution (staff, by the end of 1972 was of 130 persons, including many activities which today are given to external contractors). It was a time of discovery, learning the essentials of nuclear physics, nuclear reactor physics, nuclear radiation detection, radiological protection and small scale essays of uranium ores. Several persons of the staff were trained in France and several French researchers were invited to Brazil. By the end of this period, efforts were made in order to provide the Institution with a sub-critical heavy water facility and a thermal-hydraulic laboratory. The heavy water facility is presently being decommissioned. The thermal-hydraulic laboratory is still active, although concerned with research topics related to PWR Reactors.

American influence, started with the acquisition of the TRIGA Reactor. It was also strong during the 1970s, mainly due to the adoption of PWRs as a choice for nuclear energy supply.
A third external influence became important at the end of the 70s as a consequence of the signature of a comprehensive treaty on nuclear energy between Brazil and FRG. As a captive Research Centre for NUCLEBRAS[1], and in constant contact with German companies like

[1] NUCLEBRAS, the state owned company in charge of developing the nuclear industry in Brazil, was closed in 1989. The same activities, were taken by INB, Indústrias Nucleares do Brasil. Erection and operation of power reactors are presently a task of ELETRONUCLEAR, also a state owned company.

KWU and Research Centres like KFA-Juelich and KFK-Karlsruhe, a new culture was shaped at CDTN. Waste Management activities, started at that time, are very important up to now and there is no end in sight for them. Studies of Th-U reactor fuels were successfully accomplished in the framework of cooperative research programs. An Environmental Engineering Group was included into the Organization Chart as early as 1980. Meteorology was also introduced, due to sitting and licensing requirements of nuclear power units and fuel cycle facilities[2]. A good deal of co-operation was also established in topics like power reactor core calculations, reactor accident analysis, criticality studies. An effort to help the development of the jet nozzle Uranium enrichment process, also a joint effort with FRG, did not succeed. The ultra-centrifugation method, developed independently in Brazil at the same time, by other laboratories than CDTN, proved to be more economical for the required amount of enriched uranium (SWU).

Basic training of power reactor operators, started in the 1970s, is still going on. Nearly two hundred persons from the staff of ANGRA I and ANGRA II nuclear power units as well as from the licensing staff of CNEN were trained at the 100 kW TRIGA Mark I, Research Reactor. This small, robust system is probably the best option for teaching the basic concepts of reactor physics and operation.

CDTN into the 1990s: Manpower, programmes and infrastructure

In the beginning of the 90s, the intensity of the collaboration with FRG was sharply reduced, and a lesser demand from services by the nuclear industry, then under very heavy criticism from segments of the population, produced almost a vacuum into the institutional Research Program. Again under CNEN-the Brazilian Nuclear Energy Commission administration, CDTN started to look for ways of using the knowledge acquired into the nuclear field, as well as for alternative lines of research. Internal discussions at that time resulted in the formal draft of the institutional mission:

- To perform R&D in the nuclear and related fields, delivering knowledge, goods and services for the benefit of Society.
- Quality related issues, not only in the traditional sense of quality assurance, but "total" quality, quality involving all aspects of the Organisation and the perception that we must give some kind of return to Society as a whole became a strong feeling within the institution.

Human resources

CDTN staff, which was under 150 persons by 1970, increased to a peak of 540 around 1984, then decreased to 390 today, in despite of the admission of nearly 100 during the nineties. Retirements, due to soft legislation, and also for fear of new restrictive government legislation, were the main cause for staff reduction in the nineties. Perspectives for new job openings are virtually non existent at this time, due to severe restrictions into the Federal Budget.

A policy clearly established during the nineties by CDTN management was one of having the people to look for completion of their academic education. Accordingly, the number of Ph.D.s existing at the beginning of the decade was increased fourfold, being an institutional goal to

[2] Concern with the environment was present from the beginning, motivated by the study of underground water at the dry northeastern Brazilian regions.

reach 40 next year. Besides this, in despite of many retirements, it was possible to keep the number of persons holding a M.Sc. degree around 100. This was perceived as a condition for being consistent with the institutional mission and also as a condition for survival in the near future.

Staff reduction was up to a certain point compensated by handing few activities to private contractors, such as cleaning, physical security, air conditioning equipment, computer servicing. The productivity of the personnel was clearly increased with the introduction of a computer network accessible to all. Now, a critical point is being reached in which new ways of dealing with this situation must be found. The promising alternatives are in the sense of making partnership with the local universities, in a way that a certain number of students can develop their projects in our laboratories. Accordingly, we have several agreements with local universities, by which we also present joint project proposals to several research financing organisations.

CDTN programmes

CDTN technological projects and activities are organised around the following programmes:

- nuclear reactors
- materials science and materials engineering (including reactor fuel)
- environment
- process engineering
- waste management
- radiological protection
- human health.

The above classification is rather concerned with the purpose than with the nature of the involved technologies. The absence of a program of radioisotope applications, for instance, means that these techniques are spread through de remaining ones.

It has been a consistent policy of CDTN, in the nineties, to recognise the importance of using the laboratory infrastructure and human resources for the benefit of Society, even if the nature of the problem is such that nuclear techniques are not directly required. Nuclear techniques seldom appear or are used alone, they are frequently associated with other technologies aiming at producing results for a given problem. Hence, the expression related technologies which appears into our mission statement. Recently, this practice, which is common to other CNEN NRC' s in Brazil, has been formally endorsed by CNEN, our Mother Institution.

Infrastructure

The most important piece of infrastructure is still the 100 kW TRIGA Mark I Reactor. This reactor will complete 40 years from the first criticality in the year 2000. In the last five years, investments of nearly 500 000 US$ were made in order to have the physical installations complying with modern safety requirements. The original control desk was replaced by a new, modern one, made by IEN, one of the CNEN institutes. The scope of the works included a control room with an insulated atmosphere, the replacement of the electrical wiring of the building, adding new features to the air conditioning system and reworking of the internal reactor hall surfaces. The power increase of the TRIGA Reactor to 250 kW is in an advanced stage, pending only a survey of the fuel elements in order to detect eventual surface defects and the approval of the Safety Analysis Report.

One of the newest and most expensive laboratories is a modern system for Surface Analysis of Materials. Several techniques of surface analysis can be available from this laboratory. On a current basis, the same group also operates a modern Moessbauer system.

This year, a very low background laboratory, for environmental levels of tritium counting was added. Money for civil works came from the Brazilian Government, while the main counting equipment has been donated by IAEA. Several other modern equipment are available on a partnership basis with UFMG, the Universidade Federal de Minas Gerais. Examples of this are an electronic micro-probe and a scanning electron microscope.

A list of the other main CDTN laboratories and equipment is given in Annex 1.[3]

Main current projects and activities

Many projects are into the portfolio of CDTN at a given time. At this moment, the most relevant ones are:

1. TRIGA reactor nominal power increase from 100 to 250 kW; the first criticality of this system is dated in the logbook of the reactor supervisor as of November 1960.
2. CAFÉ, a thermal loop for irradiation of fuel and materials samples at the 5 MW pool reactor of IPEN, one of the NRCs of CNEN; pressure and temperature equivalent to those existing in a PWR reactor are to be obtained, although the neutron and gamma radiation levels are supposed to be smaller; other Brazilian research centres are also involved into this project;
3. Participation, together with other Brazilian institutions of the nuclear area, into the HALDEN reactor project, Norway; activities concerning reactor fuel element, man-system interactions and life management of reactor components are the main interest at this time.
4. Life management/life extension of power reactor components, a project supported after several years by IAEA, to which credit is a reformulation of the programme in materials engineering of CDTN;
5. Evaluation of Waste Management techniques which uses cement and bitumen as materials for waste immobilisation; evaluation of alternative matrices for the same purpose; presently, three studies are being performed under contract with the power station operator, concerning the use of cement and bitumen as matrices for waste immobilisation; this same group has had the opportunity to work a few times under contract for industrial waste process development;
6. Immobilisation of Radium-226 needles, formerly used by industries and hospitals; besides the internal programme, CDTN has been acting in several Latin-American countries, as a partner of IAEA, for the same purpose.
7. Radiation dose evaluation for nearly 5000 workers from CDTN, hospitals, industries and universities; calibration of radiological protection equipment;
8. Diagnosis of Leishmania by the use of P-32 detectors; this project also partially sponsored by IAEA;
9. Participation in DECADES, an IAEA partially sponsored project, intended to compare all the parameters involved into different energy generation alternatives;
10. Laboratory scale studies of advanced research reactor fuel;

[3] More detailed information on the available equipment and techniques can also be found at CDTN home-page.

11. Participation, together with other local institutions in several projects concerning Human Health and the Environment: air pollution studies by small pig-iron producing industries, Hg poisoning due to improperly conducted Au mining operations, etc.
12. Dissemination, among the entrepreneurs community, of the technique of gamma irradiation. Courses, conferences and advice are available to entrepreneurs and persons from the community; CDTN has already concluded plans for having his own pilot facility, a 60 000 Ci gamma irradiator. Some help on specific licensing issues of gamma-irradiators has been provided to the licensing group of CNEN. CDTN is co-ordinating the IAEA/ARCAL project dedicated to look at the legislation concerning gamma irradiation.
13. Studies for the management of underground water resources. The IAEA is a traditional partner of CDTN in the use of Tritium and stable isotopes (^{2}H, ^{18}O) techniques. CDTN has a Tritium laboratory operating for several purposes for 30 years. Presently, in order to be able to determine very low levels of natural Tritium, a new, small laboratory has been erected. IAEA donated the counting equipment. Government resources were used for the civil works. Inside the new counting room, the radiation background is only 2% of external levels, so far without the use of the sophisticated coincidence apparatus.
14. Studies of micro and nano-structured materials are currently undertaken at CDTN materials laboratories; in some cases, concepts of materials science are employed to evaluate alternative materials for waste immobilisation. In other cases, nano-structured materials are studied because of its future potentialities, even if direct connection with topics of nuclear energy is not clear.
15. The materials programme at CDTN ranks among the ones with the largest capacity of converting from nuclear to non nuclear technologies; in the beginning of the 90s, due to a very small demand from the nuclear area, in a short time, the same people and the same equipment gave origin to very nice projects, concerned with autonomous process for the development of zeolytes and alumina. An Image Analyser Software, conceived initially for the study of fuel element micro structures was improved to become a general image analyser. Applications of this code in medicine and by industry have been registered.
16. The centre has a large experience in processing (pilot scale) uranium ores. Flotation and column flotation techniques were developed up to a point in which CDTN can be considered a national reference on them. The demand from the nuclear area ceased nearly 10 years ago, and the available expertise and equipment were converted to process of different ores. In some cases, processing of industrial wastes by this technique allows the economical recovery of some of the industrial waste contents. Industrial companies are the major segment of clients for this technology.

Challenges faced by CDTN

The quality issue

Being a NRC, Quality Assurance was not a new issue to CDTN. From the 70s non-destructive essay techniques like ultrasonic waves, Eddy current, gamma-radiography and other were available on a current basis at CDTN. Presently, private companies have taken over these activities and we at the research centre are trying to connect robot arms to the transducers in order to do the same operations in hostile environments. It is generally accepted that the nuclear energy programme contributed much to the introduction of quality assurance in Brazil.

Now, in the 90s, one started to speak of "total" quality, in the sense that quality must be spread over the whole of the organisation. At the beginning, a somewhat rigid approach was tried at several places, but soon a more flexible (in my opinion) management philosophy

began to be accepted. Also based in international practices (the Malcolm Baldridge premium), the new model, now under the title of "Prêmio Nacional da Qualidade" (PNQ) is less prescriptive, more apt to get a positive response from a community of scientists and technologists. Under this concept, an organisation is evaluated by the following criteria:

- leadership
- strategic planning
- focus on the client and on the market
- information and analysis
- human resources management
- process management
- results of the organisation.

The difficulty (and presumably the merit) with this philosophy of management is that it is necessary to involve everyone from the organisation, a task not always easy to accomplish. In matters of science and technology management, CDTN has joined efforts with other research centres in Brazil. An experimental project in quality management, also based on the PNQ scheme, co-ordinated by ABIPTI, (a national association of technological research centres), is under way.[4] Assuming that all the schemes of quality management intend to increase the long term chances of survival and growing of the organisation, which will ultimately depend on its output, as a depart point for the strategic planning of CDTN[5] we have postulate that our output must have some attributes:

Quality, of products and services, translated into calibrated instruments, trained people, certified laboratories, good and readable reports delivered in due time, etc.

Originality, measured by the number of papers published by peer reviewed magazines, number of patents, and other;

Institutional image as perceived by clients and/or the general public.

Anyway, it must be kept in mind that nothing can substitute for the true knowledge of the scientific and technological issues.

Budget

In despite of the fact that that the yearly budget contains a statement for resources coming from the supply of special services to industries and other organisations, it is rather a fixed number. This practice, which is related to legal dispositions, does not help in motivating the scientists and technicians to transfer more of their knowledge to Society. We know that this is not exclusive of Brazilian organisations. Exceptions are being admitted at a few institutions, but so far they have not reached CDTN or CNEN.
Gross budget number for 1998 was around US$ 18 million. Resources from research financing organisations and invoices from selling special services accounted for nearly 9% of this total.

[4] ABIPTI herself is affiliate to WAITRO, the corresponding international association.

[5] At this moment we are at CDTN recycling our strategic planning. Employees are asked to contribute, on a voluntary basis, forwarding their viewpoints on the strengths and limitations of the organisation and what are the challenges and opportunities presented by the external environment.

Library

Keeping updated collections of scientific magazines is a permanent challenge for a research centre in a developing country, specially for a interdisciplinary institution. The purchase of books or pieces of new equipment many times can be postponed for the next year, but the same is not true for scientific magazines. From a top level of 150 publications in the seventies, CDTN Library is today struggling to keep some 100 titles on a current basis. The electronic libraries show some promises for the future, but so far, when available in electronic versions, scientific magazines bear the same or slightly higher prices than the paper version. This is a universal problem with no easy solution.

Holding to the fundamentals

Nuclear energy and applications of nuclear radiation are already on a mature phase. Probably due to this, and to the fact that nuclear equipment is more and more apt to be used by the lay person, my personal feeling is that there is a tendency among the technologists to learn only superficially the fundamentals of nuclear energy and those of nuclear radiation detection. As a result, a loss of expertise may happen, with a potential for the introduction of safety issues and superficial interpretation of experimental results. We look at this as a challenge and also as an opportunity to the NRCs.

New directions

Looking for new directions, one should not miss the IAEA document GOV/1999/37, "Medium Term Strategy", although in this discussion paper we rather speak of our own experience.

At this moment, CDTN and other NRCs in Brazil benefit from the fact that the nuclear energy programme has been reactivated. ANGRA II, the second nuclear power station, (1200 MW(e)) is nearing conclusion and many admit that the third power station will also be erected. The fuel element company (INB) is in the final stages of incorporating the reconversion to UO2. The potential interest in high burn-up fuel and in Life Management of Reactor Components offer good opportunities, even for the small research centre, provided that the expertise is there. This means that a number of issues in nuclear power are or will be available to the research centres: the waste management problem, environmental monitoring, modernisation of control rooms designed in the 70s, issues related to safeguards measurements, particular cases of accident analysis, etc.

In Brazil, even in the absence of strong nuclear energy programmes a large space is available for the research centre. Medical applications of radioisotopes for diagnosis and therapy, specially short lived radionuclides, present an increasing demand. Over 1,4 million medical procedures a year are performed in Brazil[6] and it would be desirable to double this number in a short time, if we intend to reach levels of advanced countries and even of our neighbour Argentina. The search for more and more sophisticated ways of producing and applying radiopharmaceuticals certainly offers opportunities for the medium sized research centre. The

[6] Most of the radiopharmaceuticals used in Brazil are prepared by the Instituto de Pesquisas Energéticas e Nucleares-IPEN, one of the CNEN institutes. Part of this material is imported. Short lived materials are produced in a cyclotron.

presence of medical professionals is of paramount importance in this line of work, but other specialists are required as well.

The area of energy generation presents opportunities as well. If the country foresees an interest in nuclear power generation, the follow-up of other countries initiatives on concepts of advanced reactors, safeguards, non-proliferating reactor fuel, extended fuel burn-up, Life Management Studies, are certainly relevant tasks. Similarly, it would be worthwhile to speculate on the impact of some of the new technologies on power generation at large (superconductivity, microelectronics, solar energy).

Environment is an area where new opportunities of using the skills learned in the nuclear field arise everyday. Besides that, it is quite probable that the energetic options in the future will be strongly influenced by multi-parameter evaluation of the different alternatives. Involvement of the NRCs in initiatives like the DECADES project and many other research opportunities will always be beneficial to the country.

If the NRC has a good tradition in materials science and/or materials engineering, the lack of demand from the nuclear field would be replaced in a short time by many other possible clients. Some of the accomplishments of CDTN in this area were already mentioned. Process Engineering, if concerned with ore processing, would always have good opportunities in countries having ore deposits of economical interest. The column flotation technique offers good opportunities even for the recovery of certain materials present in industrial waste.

Waste management, which includes also a philosophy of waste classification and interim storage, already is a capacity sought for by the market. New directions for this CDTN group would be quickly found, if necessary.

Human health, or more precisely, the use of nuclear radiation in topics related to human health, is new as a research area at CDTN. When this group started, a few years ago, we required that only projects presenting a relevant use of nuclear radiation should be proposed, so that our work would be complementary rather than a duplication of the research already performed at the Brazilian universities. Given this orientation, a few projects were already presented, and interesting results are being displayed, at a cost/benefit relationship very favourable.

Radiological protection specialists are already in great demand from the general public, hospitals and State Authorities. On a first moment we see our duty as one of attending to a diversified demand in personal and environmental dosimetry and safety inspections of new laboratories and clinics; steps are being taken to transfer this activities to the private initiative and keeping the ones which requires investments not affordable by small companies. In due time, this should enable us to do some more research work in the area.

Conclusion

Maturity of Nuclear Energy as well as the eventual phase-out of the nuclear option may pose a problem to nuclear research centres, in the sense that their projects might become out of context in both cases. Our experience at CDTN is such that, as soon as the research centre becomes involved with technological issues of the community, its expertise will be of invaluable help and the non-nuclear projects will find a place side to side with the nuclear

ones. There are conditions to be fulfilled if this outcome is desired. The first one is that a certain number of interdisciplinary persons be available among the body of researchers. Interdisciplinary projects are among the ones who offer good opportunities at reasonable costs for a developing country. Up to now, interdisciplinary experience was possible only by uniting a large number of specialists from different areas. From now on, with the almost universal policy of job curtailment, the research centres must be able to find this kind of generalist professionals, coming out of the graduation and post-graduation university courses.

Cultural issues and insufficiency of seed money may nullify efforts of the organisations to put forward joint projects and programmes. Enters into evidence the interdisciplinary professional who is able to put forward joint inter-institutional projects. This kind of person would be the one able to find new clients, new partners as well as to smooth the cultural differences among groups.

Coming to the issue of the international co-operation, we at CNEN/CDTN are proud that we have been able to establish a partnership with the IAEA in order to help some Latin-American countries to store in a safe way the existing inventory of Ra-226 needles. This is a material no longer in use worldwide and poses severe risks to workers and to the community. On occasion, our experts in hydrology have been able to act as IAEA experts in African countries. We are also very keen on having been able to get technical support and sometimes equipment from IAEA. Our previous explanation evidenced only partially the number of projects in which this help came and was useful. By making their resources (including expertise) available, the developed countries are major contributors to the IAEA projects. Enhancement of their support could make a positive difference in the developing countries.

Nuclear research centres do have a role in disseminating balanced, non-partisan and non-emotional information relative to the merits and challenges of nuclear energy. At CDTN, we have been concentrating our efforts into two areas: (1) objective technological information, collecting data from several energy alternatives, such as the model of the DECADES and other similar projects; (2) information to the lay person, via television interviews, visits of students, and so. In the last three years, an open-door event was held, with the participation of 1500/2000 visitors each time.

ABBREVIATIONS

ABIPTI, Brazilian association of technological research centres
ANGRA 1, ANGRA 2, Nuclear Power Stations in Brazil, PWR type
BNL, Brookhaven National Laboratory
CDTN, Centro de Desenvolvimento da Tecnologia Nuclear, one of the CNEN nuclear research centres
CNEN, Comissão Nacional de Energia Nuclear (the Brazilian Nuclear Energy Authority)
DECADES, an IAEA project aimed at evaluating different energy alternatives
FRG, Federal Republic of Germany
IAEA, International Atomic Energy Agency
INB, Indústrias Nucleares do Brasil, state owned company presently in charge of fuel element fabrication and the exploitation of Uranium reserves
IPEN, one (the largest) institute of CNEN

KFA, Kernforschungzentrun Anlage, Julich, Germany
KFK, Kerforschungzentrum Karlsruhe, Germany
KWU, Kraftwerk Union
NUCLEBRAS, Empresas Nucleares Brasileiras, the State owned company formerly in charge of establishing the industrial nuclear energy sector
PNQ, Prêmio Nacional da Qualidade, the national award for excellence in management
PWR, Pressurized Water Reactor
UFMG, Universidade Federal de Minas Gerais
UFZ, Umwelt Forschungszentrum, Leipzig-Halle
WAITRO, World Association of Technological Research Institutes

Annex 1

CDTN MAIN LABORATORIES AND INSTALLATIONS

Corrosion
Dimensional Metrology
Dosimeter calibration (including radiation sources donated by IAEA)
Environmental radiometry analysis
Gamacell
Gas adsorption
Hydrology, Geohydrology and Sediment Evaluation
Image Analyser Software
Materials and Nuclear Fuels (chemical processing of fuels, ceramic and polymeric materials, ceramography, pelletization and sintering of ceramic materials, fuel pellets and fuel rod fabrication, flash laser)
Mechanical essays (Instron type machines for tension/deformation curves, materials fatigue, Charpy instrumented machines, fluence machine, 1000 kN Kratos machine, rotative fatigue machine, etc)
Mechatronics
Metalographic analysis
Non-destructive essays
Nuclear Measurements
Physical essays of ores (lab and pilot scale)
Preparation of ore samples for analysis and pilot runs
Radiobiology
Radiochemistry (neutron activation, gamma-ray spectrometry)
Solvent Extraction and Leaching
Stress and vibration analysis
Surface Analysis and Mössbauer technique
TRIGA Reactor
Thermal-hydraulics
Tritium (non-environmental) and Carbon-14
Waste management (waste immobilisation by cement, bitumen, and polymers, leaching)
Welding, Mechanical Works, Mechanical Projects
Chemistry Laboratories *(atomic absorption, liquid and gas chromatography, potentiometry, UV-VIS spectrometry, X-Ray fluorescence spectrometry, Gravimetry, Volumetry, electron microprobe, ICP-AES,...)*