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The brazilian national laboratory for synchrotron light

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ABSTRACT. In this paper we describe the Brazilian synchrotron light source - Laboratório Nacional de Luz Sincrotrón/LNLS - located in Campinas, Brazil, and review its present status. LNLS is a National Laboratory of the Brazilian National Council for Scientific and Technological Development (CNPq). We discuss the strategy for setting up LNLS and comment on its relevance for the scientific and technological development of Brazil. We present a brief description of the storage ring and its commissioning. We also present a description of the beam lines and scientific instrumentation. Seven beam lines, many of them proposed by external users and financed by external agencies based on competitive grants, will be in operation by early 1997. An eighth beam line, for X ray fluorescence, was funded recently, for operation in 1998. LNLS is a facility open to all qualified users, based on peer review of projects. Academic users from Latin America will have free access to photons provided by LNLS.

RESUMEN. En este artículo se describe la fuente brasileña de luz sincrotrón —Laboratorio Nacional de Luz Sincrotrón, LNLS— ubicado en Campinas, Brasil, y se menciona su estado actual. El LNLS es un laboratorio nacional del Consejo Brasileño de Desarrollo Científico y Tecnológico (CNPq). Se discute la estrategia para la instalación del LNLS y se comenta su relevancia para el desarrollo científico y tecnológico de Brasil. Presentamos una descrición breve del anillo de almacenamiento y su distribución. También presentamos una de las líneas de haces de luz y su instrumentación científica. En 1997 entrarán en operación siete líneas, la mayoría de las cuales fueron propuestas por usuarios externos y financiadas por agencias también externas en base de patrocinios obtenidos bajo convocatorias. Recientemente fue aprobada una octava línea, para uso de fluorescencia de rayos X y operará en 1998. LNLS es un laboratorio abierto a los usuarios calificados bajo proyectos calificados por pares. Los académicos de Am'erica Latina tendrán acceso libre a los fotones ofrecidos por el LNLS.

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1. INTRODUCTION

Since 1987, the National Council for Scientific and Technological Development (CNPq) has been engaged in one of the largest scientific projects ever undertaken in Brazil—the design and construction of a synchrotron light source in the Laboratório Nacional de Luz

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Sincrotrón. This effort is now approaching conclusion, with the commissioning of the 1.15 GeV electron storage ring, which began in May 1996, and the installation of the first beam lines for experiments. Until now, about US$50 million have been invested in the construction of the storage ring and beam lines.

In this contribution, we first discuss briefly the motivation of the project and then present some technical information about the storage ring and the beam lines.

Building capability to do high level research and development is one of the most important functions of large scientific projects in a developing country. In the context of the somewhat rocky road of research funding in Latin American countries, the long term continuity and eventual success of LNLS demonstrates some very welcome changes in the Brazilian national system of science and technology. One of the preconditions for building up a large, committed, and relevant community of scientists and technologists in a developing country is the cumulating of small (positive) changes in the long run. Large fluctuations, which are frequently negative, are prejudicial to the development of any significant research activity in a country, particularly those which require long times for reaching maturity. LNLS is a project which has had scientific and administrative continuity under five major changes in the Brazilian federal administration, nine Ministers of Science and Technology, and six Presidents of CNPq. This is clear evidence that it is already possible to plan for the long term development of science and technology in Brazil, in spite of the usual short term turbulences.

Conceptually, the Brazilian project was based on a strategy combining engineering, science, and organization. Engineering meant designing and building as much as possible of the storage ring and instrumentation in Brazil, with the help, whenever possible, of local industry. The idea was to have accelerator technology, without going into costly high-energy physics. This settled the choice for Science: materials science done with photons from an electron storage ring. The innovation in organization was the concept of a national laboratory. A synchrotron light source would serve a broad community—practically all disciplines in exact, life, and earth sciences would benefit.

The engineering leg of the strategy depended on a huge bet: that in a short time LNLS could train its staff to design and build the accelerators. Ricardo Rodrigues, a young physicist from the University of São Paulo, was given the task of running the construction of the accelerators (with very profitable side incursions into everything else!). At this point, an option was made: LNLS would train its staff in-house as much as possible—there was no time to send people abroad for extended training periods, whatever experience they gained would not be immediately applicable to the working environment in Brazil, and construction had to start immediately. This decision was complemented by two related ones: (1) send technical staff abroad for short periods, to learn specific technique or to solve clearly defined problems, after they had tackled the difficulties by themselves for a while; (2) from time to time have experts review the project (for a variety of reasons this actually happened only twice—in 1989 and again in 1991).

As to the Science leg of the strategy, LNLS had to start by building up an users' community. CNPq, let us recall, was created in the early 50's. Influenced by the post-war American example and constrained by the lack of industrial demand for R&D, it emphasized support for basic research. Thanks to its efforts, over the last four decades, Brazil built up a small, but politically visible, scientific community. In the meantime,

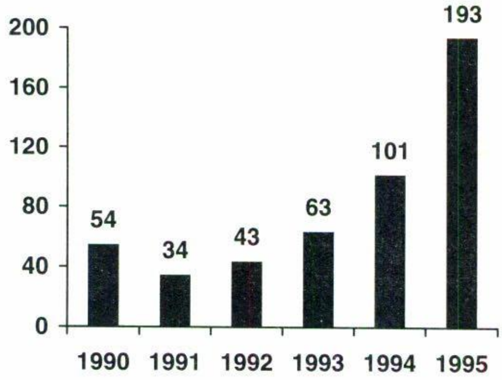

FIGURE 1. Number of participants in the Annual Users' Meeting of LNLS.

industrial development was geared to imported technological black boxes and turnkey installations, so that science has remained largely isolated from mainstream economic life. For most scientists, technology still smacks of lower quality, not a calling for higher talents and better brains, which should concern themselves with the deeper secrets of the Universe. This led to the somewhat paradoxical situation in which, on the one hand, it was easy to rapidly build a community of users and, on the other, there was widespread initial opposition to the idea of building a synchrotron light source.

Late in 1986, Aldo Craievich accepted to be Deputy Director of LNLS. He was made responsible for the scientific program. Hence, in parallel with the effort to build the accelerators, LNLS began a series of workshops to "market" research with synchrotron light sources. These topical workshops, in addition to advertising LNLS and the potential of light sources as research tools, allowed the local community to establish useful links with users abroad. This was instrumental to increase the number of trained users in Brazil. Figure 1 shows the evolution of the number of participants in the Annual Users' Meeting. What is not show, but is perceptible to those who have followed these meetings, is the qualitative evolution in the profile of participants, thanks to the training obtained in foreign synchrotron light laboratories.

The development of scientific instrumentation for using synchrotron light has been one of the main concerns of the Scientific Department of LNLS over the years. The existence of a reasonably strong research basis in the country made it possible to rapidly form high quality groups for VUV and X-ray instrumentation. This also allowed a considerable reduction in the cost of beam lines - so much so that, in spite of severe budgetary constraints, LNLS has seven beam lines due to come into operation soon after synchrotron light becomes available and the design of its 4-crystal high resolution X-ray monochromator was copied by the European Synchrotron Radiation Facility. In 1992, thanks to Volker Sailes enthusiastic support, LNLS installed its first beam line at the Center for Advanced Microstructures and Devices of Louisiana State University in Baton Rouge. To our knowledge, this was the first time that a complex scientific instrument manufactured in Brazil went North across the Equator. More recently, LNLS won a bid to supply CAMD with a mirror chamber for a VUV beam line, competing with traditional suppliers in the field.

The third slice of the strategic pie turned out to be, as expected, the most difficult. There was no previous experience with a National Laboratory for physicists, chemists, biologists, and other specialists. The prevailing culture was that of small science, done in a compartmentalized way. Laboratories in University Departments were (and still are) very much self-contained. Hence, the reaction of the establishment against LNLS was strong—it was seen as an unfair competitor for resources, dominated by a bunch of insolent youngsters. The idea that it could be something different—a laboratory operated on a professional basis, managed for efficiency and pooling of scarce resources, with allocation of time based on peer review of qualified projects was entirely foreign to the majority of the scientific community. Even the Brazilian Physical Society publicly opposed LNLS. The staff quickly learned that technical problems are trivial compared with cultural ones. Fortunately, opposition got swamped by the growth of the scientific community—the younger generation without vested interests to defend supported LNLS. Influential scientists who initially opposed the project, eventually changed their minds.

The concept of a national laboratory, concentrating resources, but offering free access to a large fraction of the scientific community of a developing country may be the most important fringe benefit of a synchrotron light source. National laboratories are a cost effective way to speed up the development of research of a country, provided they are outward looking in their policies. In addition, the ample spectrum of disciplines which can be covered by synchrotron light research is a vital element for the decision to build such a facility.

LNLS is open to all Latin American users. Projects will be selected for their quality and scientific interest, not for their national origin. Academic users from outside Brazil will have free access to photons, just like Brazilian users. They are only expected to pay for the cost of setting up and performing their experiments, not for access to the light source. By teaming up with groups which already have appropriate instruments, the cost may be further reduced. The Annual Users' Meeting [2], normally held in the month of November each year, is the best place to learn more about LNLS and meet other researchers interested in using the light source.

2. STORAGE RING

The LNLS synchrotron light source is based on an electron storage ring with 1.15 GeV nominal energy. The actual maximum energy may exceed 1.37 GeV and may reach 1.5 GeV with an upgrading of the power supplies. In practice, the design energy of 1.15 GeV has proven very conservative, due to the good field quality of the magnets produced by LNLS. Most of the components (magnets, power supplies, vacuum chambers, septa, kickers, monitors, control system) were manufactured in-house. The storage ring was assembled between October 1995 and April 1996 and turned on, for the first time, in May 1996.

As an example of the way the storage ring was built, the steel laminations for the magnets were laser cut in-house. This is an innovative technique for producing storage ring magnets, which proved to be reliable and economical for R&D work and for relatively small production runs. It also allows for greater flexibility in the design of the magnets.

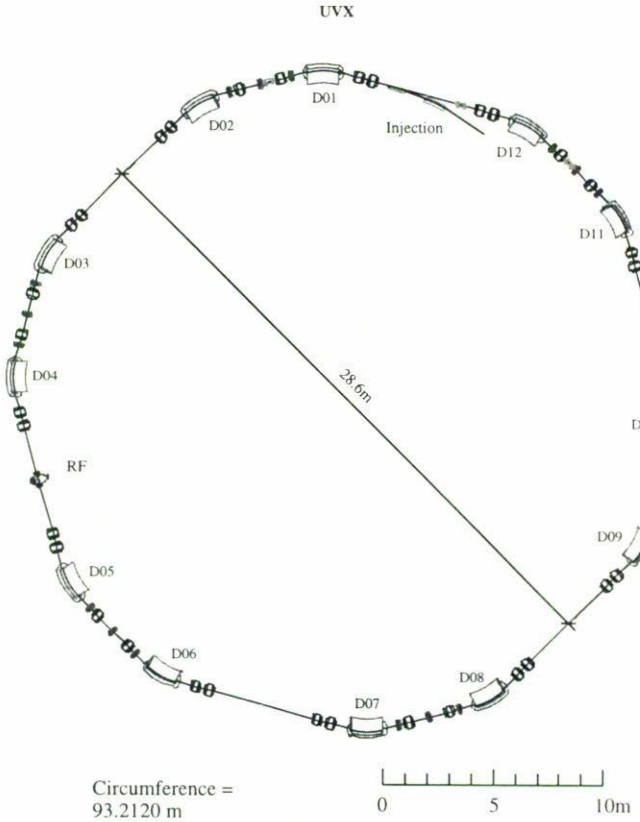

FIGURE 2. Lay-out of the UVX storage ring.

For instance, the dipoles are curved (staggered laminations), but held together by straight tie-rods, so each lamination is specifically cut for its place in the magnet, something which would be much harder to do by the traditional stamping method. In addition, the external laminations of all magnet cores are shaped (Rugowsky contours) to minimize edge effects.

The layout of the storage ring is shown in Fig. 2 and the main parameters are summarized in Table I.

The storage ring has several different operation modes which have been studied from the beam dynamics point of view and which can be implemented, since the necessary flexibility of the power supplies is available. There are 6-fold symmetric modes with natural emmitances: 35, 70 and 125 nm·rad. There is one 3-fold symmetric quasi-isochronous mode, for which the momentum compaction factor is reduced by a factor of 100 with respect to the conventional modes just mentioned. This implies a bunch length of 6 ps (FWHM). The natural emittance for this mode is 286 nmrad. Finally, there is a 2-fold symmetric mode, with natural emittance of 70 nm·rad, for which the minimum full gap, which does not limit acceptance, at the middle of two opposite straights, is 7 mm. This mode will be used to explore miniaturized insertion devices. Further details about the storage ring may be found in Ref. 3

TABLE I.

Magnet lattice	6-fold symmetric, Chasman-Green
Energy (nominal/maximum)	1.15/1.37 GeV
Injection energy	120 MeV
Nominal current (multibunch mode)	100 mA
Circumference	93.212 m
RF frecuency	476 MHz
Critical photon energy	1.23/2.08 keV
Maximum number of beam lines	
Bending magnets	12 @15° source points
	12 @4° source points
Insertion devices	4 lines, dispersion free sections
	(2.95 m maximum length)

Since commissioning began in May 1996, beam dynamics studies are being performed, in order to fully understand the behavior of the machine under various operating conditions. Some of the main results are: first injection took place on May 19; the first turn was observed on May 22; the first thousand turns were observed in May 30; lifetime at injection energy of 120 MeV reached 80 seconds a few weeks later; the beam was accelerated to 1.2 GeV on July 30; and, finally, the first accumulation was observed on August 23. The experiments performed to measure the parameters of the storage ring indicate the expected disagreements between theory and experiment at low energies, due to remanent fields in the magnets. Above 370 MeV, the agreement is quite good. The major problem faced thus far the accumulation of the design current at the low injection energy of 120 MeV. It may be necessary to upgrade the LINAC injector to higher energies before the design current can be reached.

3. BEAM LINES

Initially, seven beam lines will be installed. All of them have already been built or are under construction. Two were operated at the Center for Advanced Microstructures and Devices (CAMD) of the Louisiana State University in Baton Rouge, LA. Recently, a group from the Chemistry Department of the Universidade Estadual de Campinas obtained funding for an eighth beam line, dedicated to X-ray fluorescence. This beam line will be built and operated in collaboration with the X-ray group of the FaMAF, Universidad de Córdoba, Argentina.

Below, we summarize the information about the beam lines.

In Figure 3, we show the photon spectrum from the bending magnets and an 11-pole wiggler, as well as the energy ranges of the various monochromators built at LNLS.

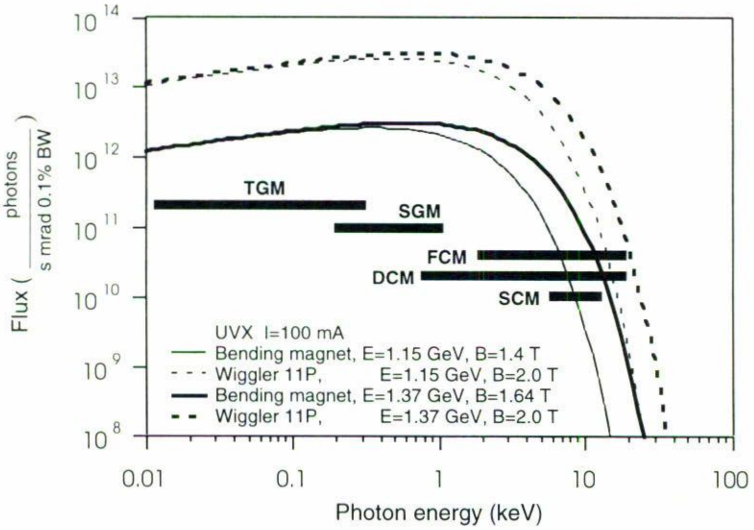

FIGURE 3. Photon spectrum from bending magnets and 11-pole, 2 T, wiggler, for 1.15 GeV and 1.37 GeV electron energies operating modes. Note the photon energy ranges covered by the various monochromators: toroidal grating (TGM), spherical element (SGM), 1-bent crystal (SCM), 2-crystal (DCM), and 4-crystal (FCM).

3.1. TOROIDAL GRATING MONOCHROMATOR

This beam line is designed for users in Surface Physics and Chemistry, Atomic and Molecular Spectroscopy, and Electronic Structure of Condensed Matter. The monochromator consists of three toroidal gratings, covering the photon energy range from 12 to 300 eV (1000 Å to 120 Å). The spectral resolution is better than 0.1 Å (40–120 Å), better than 0.3 Å (120–360 Å), and better than 1.1 Å (360–1000 Å). The flux on the sample (1.3 GeV, 100 mA) is 10^{13} photons/sec. The detectors for this beam line are: electron energy analyzer, fluorescence detector, and electron time of flight. These equipments were in operation at CAMD/LSU, until early 1996. They have now been re-assembled at LNLS.

3.2. SPHERICAL GRATING MONOCHROMATOR

This beam line is dedicated to high-resolution VUV and soft X-ray spectroscopies, the study of electronic and magnetic properties of materials, in addition to Surface Physics and Chemistry, Atomic and Molecular Spectroscopy, and Photochemistry. The monochromator is based upon two spherical gratings and covers the photon energy range from 200 up to 1500 eV with a spectral resolution better than 3000. The detectors are an electron energy analyzer, channeltrons, and microchannel plates. This beam line is under construction at LNLS.

3.3. SOFT X-RAY SPECTROSCOPY

This beam line uses a 2-crystal monochromator manufactured in-house. For details about this monochromator, see Ref. 4. It has been in operation at CAMD since 1994 with very satisfactory results. LNLS will provide CAMD in the future with an upgraded version (UHV compatible) of the 2-crystal monochromator for permanent installation in a X-ray absorption spectroscopy beam line.

Photon energy ranges: 790–1550 eV (beryl), 1480–1800 eV (quartz), 1680–2000 eV (InSb), and 2050–4000 eV (Si). The energy resolution is of the order of 0.2 eV at 800 eV (resolution power of 4000). The detectors are total electron yield, electron energy analyzer, and photodiode array.

This station will be used mainly for soft X-ray spectroscopy of transition metal and rare earth compounds (thin films, multilayers, alloys and compounds) and core level spectroscopy.

3.4. X-RAY ABSORPTION FINE STRUCTURE (XANES AND EXAFS)

This beam line uses 2- and 4-crystal monochromators, also manufactured at home. The 4-crystal monochromator is described in Ref. 5. It is interesting to observe that its design has been copied and adapted by European Synchrotron Radiation Facility in Grenoble, France, where it is known as the "Brazilian" monochromator.

The photon energies range from 2–18 keV. The detectors are ion chambers, fluorescence and electron detectors.

This station is of particular interest to chemists and for chemical analysis of materials. It will be used to study the local atomic structure of disordered materials (glasses, multilayers, composites, etc.) and the electronic and magnetic properties of materials.

3.5. X-RAY DIFFRACTION

This beam line also uses the 2- and 4-crystal LNLS monochromators (see Ref. 3).

The photon energies range from 2–18 keV. The detectors are scintillation, Si-Li solid state and linear position-sensitive detector, ion chambers, fast counter, and fluorescence detector.

This station is dedicated to multiple-axis goniometry for the study of rocking curves, standing waves, backdiffraction, topography, multiple diffraction, grazing angle incidence, θ and 2θ goniometry, Debye-Scherrer powder diffraction, textures, structural characterization of epitaxial layers and nanostructures. Planned studies cover also metal and alloys high temperature corrosion and recrystallization.

3.6. SMALL ANGLE X-RAY SCATTERING (SAXS)

The monochromator for this beam line is a horizontally bent and asymmetrically cut Si crystal monochromator (LNLS design and manufacture). For details, see Ref. 6.

The photon energies range from 6 to 12 keV with a resolution of $E/\Delta E = 5000$. The detectors are one-dimension and two-dimension position-sensitive gas detectors, and scintillation monitors.

This is one of the most "popular" stations, which will be used for the study of heterogeneous materials, characterization of fractal structures, microporous materials, microphase separation, composite glass-semiconductor nanocrystals, gels, and proteins in solution.

3.7. PROTEIN CRYSTALLOGRAPHY

The monochromator is a horizontally bent and asymmetrically cut Si crystal monochromator (LNLS design). The detector is an imaging plate.

Structural molecular biology is a rapidly growing field in Brazil, where there is interest in the study of tropical diseases and genetic engineering for tropical agriculture. LNLS is forming an in-house group which will, in cooperation with several University research groups, further develop techniques for data collection and analysis for high resolution structure determination of crystallized proteins and other macromolecules of biological importance. The possibility of using softer X-rays for structural and chemical analysis of biological materials will be explored by this group.

There are several other research projects which have been proposed to LNLS, adding up to more than fourteen stations (some to be installed in beam lines yet to be designed and built) from institutions in Brazil and Argentina, which are described in more detail in Ref. 7. In particular, we should mention the X-ray fluorescence experimental station-a collaboration between the Physics Department of the University of Córboda (Argentina), the Laboratori Nazionali di Frascati (Italy) and LNLS, and the station for analysis of residual stresses in materials to be operated by the Argentinean Atomic Energy Commission. The first of these stations is ready and will be initially installed on the XRD beam line but will soon move to a beam line dedicated to fluorescence. The second station, when available, will be installed on the XRD beam line.

4. INSERTION DEVICES

Four of the non-dispersive straight sections of the ring are reserved entirely for insertion devices. These can be up to 2.9 m in length. Additional ID's—but much shorter—may be accomodated in the remaining free spaces of the straights reserved for injection and RF cavities. At the moment, no in-depth study has been done of the devices to be used in the ring—except to the extent that the ring optics has been designed with sufficient flexibility to accomodate them. A very simple prototype of a pulsed minigap undulator has been built, but not tested in the storage ring. In the future, it may be necessary to upgrade the RF system in order to make full use of insertion devices. For this reason, LNLS is developing the capability to build its own RF cavities.

Due to the large X-ray community in Brazil, there will certainly be at least one wiggler installed at the earliest possible date, in order to increase the flux of harder photons. Consideration is being given to a superconducting 5-pole wiggler, in addition to an 11-pole, permanent magnet, device.

5. CONCLUSIONS

As far as the organizational mission of LNLS is concerned, in the past nine years a great effort has been spent in training future users - some of the results of this effort are visible at the Annual Users Meeting, which had 200 participants in 1995, most of which have had hands-on experience with synchrotron light sources, and in the projects described in

Ref. 5. This is, of course, only the beginning, as the community of synchrotron light users is growing constantly and will expand considerably in Brazil and Latin America over the next decade. It is interesting to observe that LNLS is in a privileged position compared with recently commissioned light sources as regards the scientific program, both in the number of beam lines and of projects actually underway in the start-up phase of the Laboratory.

One of the original aims of LNLS was the participation of local industry in the construction of the facility. Our experience, in this respect, has been somewhat similar to that of the first CERN acelerators, in that high-technology components had to be designed, prototyped and built in-house [8]. However, local industry has participated in supplying many materials, components and equipments, so that imports did not exceed about 15% of the overall cost of the project.

In conclusion, we can say that the Brazilian effort over the past nine years to develop accelerator engineering and scientific instrumentation for synchrotron light sources has allowed the country to build a solid base from which to take off into more sophisticated and complex technologies in the future. The path chosen for LNLS confirms the idea that the best way to develop technology is the hands-on approach and that the acquisition or donation of "black boxes" from abroad, although it may seem initially a cheaper, quicker and more desirable way to get access to state-of-the-art technology (which is rarely the case, anyway) is in the long run highly damaging to the scientific and technological development of a country.

ACKNOWLEDGMENTS

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REFERENCES

1. This Introduction has been adapted from a paper by the author, published in *Beam Line Magazine, SLAC, Spring-Summer 1996.*
2. Further information may be obtained from secre@mvx3100.lnls.ansp.br or from LNLS' home page http://www.lnls.br.
3. Liu Lin, Ed., "UVX Parameter List, Version 2", LNLS-CT-17/94.
4. H. Tolentino, A. R. D. Rodrigues, C. Cusatis, and I. Mazzaro, *Synch. Rad. News,* **6** (1993) 28.
5. H. Tolentino, A. R. D. Rodrigues, *Rev. Sci. Instrum.* **63** (1992) 946.
6. L. A. Bernardes, H. Tolentino, A. R. D. Rodrigues, A. Craievich, and I. Torriani, *Rev. Sci. Instrum.* **63** (1992) 1065.
7. Scientific Department/LNLS, Ed., "Outline of LNLS Beamlines and Workstations", LNLS-NT-01/94.
8. B. Southworth, "Industrious Approach", CERN Courier, June 1992, p. 12.