The IEA-R1 Research Reactor: 50 Years of Operating Experience and Utilization for Research, Teaching and Radioisotopes Production

R.N.Saxena

Research Reactor Center
IPEN-CNEN/SP-Brazil

"International Conference on Research Reactors: Safe Management and Effective Utilization"

Sydney, Australia, 5-9 November 2007


Relevant Facility Background
and
Principal Areas of Utilization

The Reactor Building

Constructed by Babcock-Wilcox, IEA-R1 is a swimming pool type reactor, moderated and cooled by light water and uses graphite and beryllium reflectors

The Reactor was commissioned on September 16, 1957 and achieved its first criticality. The reactor is currently operated at 3.5MW on a 64h per week cycle.

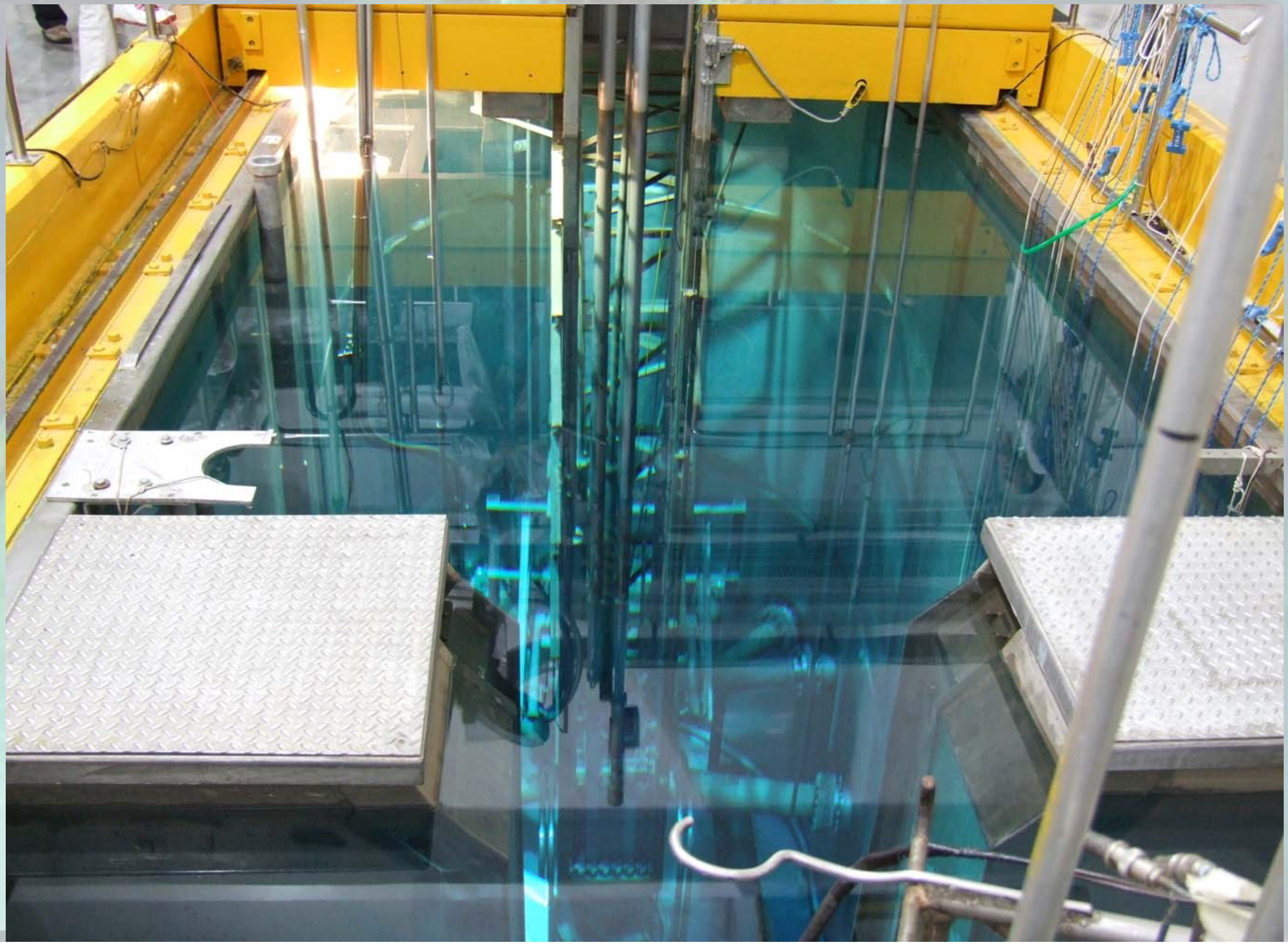
The fuel elements with 20% enriched uranium (U_3O_8-Al, 2.3g/cm^3) and (U_3Si_2-Al, 3.0g/cm^3) are produced at IPEN.

Brazilian Research Reactors

	IEA-R1	IPR-R1	Argonaut	IPEN/MB-01
Criticality	1957	1960	1965	1988
Operator	IPEN-CNEN	CDTN-CNEN	IEN-CNEN	IPEN-CNEN
Location	São Paulo	Minas Gerais	Rio de Janeiro	São Paulo
Type	Swmming Pool	Triga Mark-1	Argonaut	Critical Assembly
Power	2-5 MW	250 KW	500 W	100 W
Fuel Enrichment	20%	20%	20%	4.3%
Supplier	Babcock Wilcox	General Atomics	USDOE	IPEN

The IEA-R1 is the only research reactor in Brazil with substantial power level suitable for utilization in scientific research in physics, chemistry, biology and engineering as well as for producing some useful radioisotopes for medical and other applications

A View of the top floor of the Reactor



The Research Reactor Center – CRPq is responsible for the operation, maintenance and utilization of the IEA-R1 reactor

The Research Reactor Center has a three-fold mission

- ✓ promoting basic and applied research in nuclear and neutron related sciences
- ✓ providing educational opportunities for students in these fields including Post-graduate and under-graduate teaching
- ✓ Providing services and applications resulting from the reactor utilization and radioisotopes production for medical and industrial applications

Major programs at CRPq

- ✓Nuclear and condensed matter Physics
- ✓Neutron activation analysis
- ✓Operation and utilization of reactor
- ✓Nuclear Metrology
- ✓Under-graduate and post-graduate teaching
- ✓Training of reactor operators
- ✓Modernization of reactor

Personnel

Research Staff	23
Technologists	27
Technicians	19
Secretaries	02
Total	**71**

Qualifications

Ph.D.	23
M.Sc.	11
Reactor Supervisors	07
Reactor Operators	11
Engineers	02

Resident Health Physics Group

Supervisors	04
Technicians	08

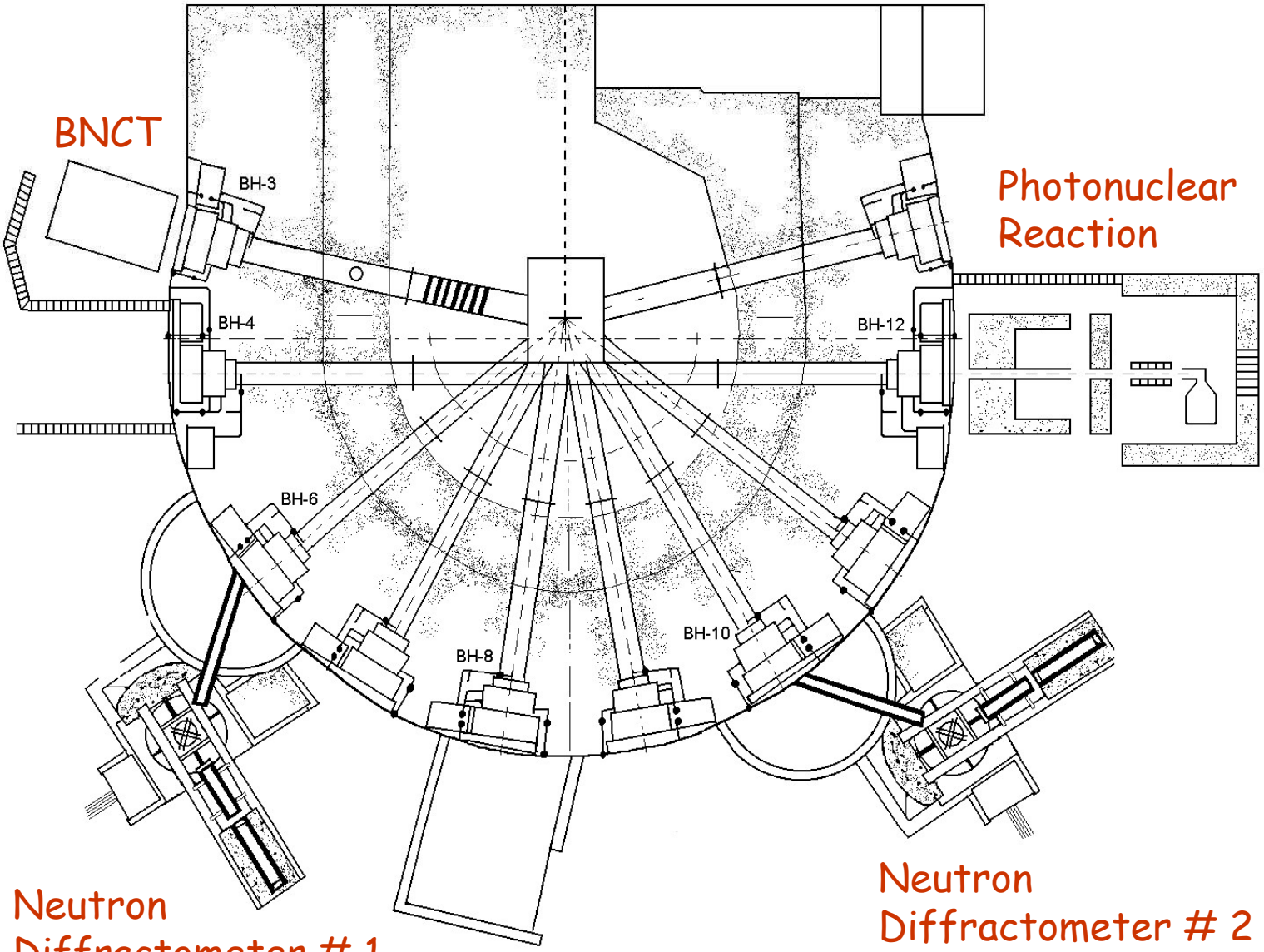
R&D activity at CRPq

Scientific programs at CRPq span several multidisciplinary, fundamental and applied research areas

Specific research programs include:

- ✓Nuclear structure study
- ✓Nuclear and neutron metrology
- ✓Neutron diffraction
- ✓Nuclear hyperfine interactions
- ✓Neutron activation analysis
- ✓Neutron radiography
- ✓Nuclear instrumentation

Neutron beam Utilization - 1st floor of the Reactor

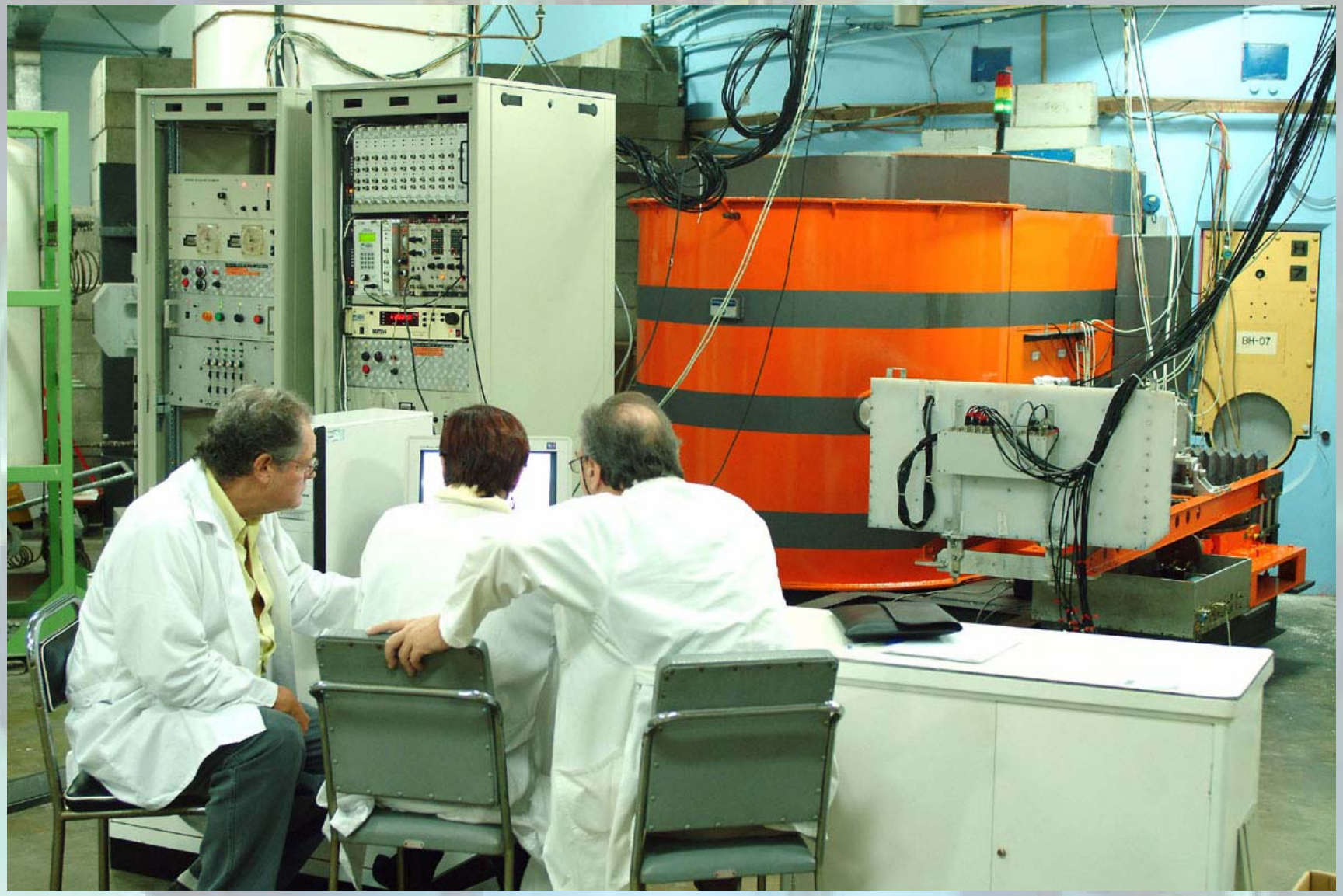


Neutron Diffractometer

A major program to upgrade the neutron diffractometer installed at IEA-R1 research reactor was concluded. It includes:

- ✓ Stack of position sensitive detectors (PSD),
- ✓ A rotating oscillating collimator,
- ✓ An elastically bent silicon single crystal focusing monochromator

The PSD stack will permit simultaneous measurement of neutron intensity in an angular interval of 30 degrees. The monochromator will permit the choice of three different neutron wavelengths.



Final adjustments and tests of the diffractometer systems

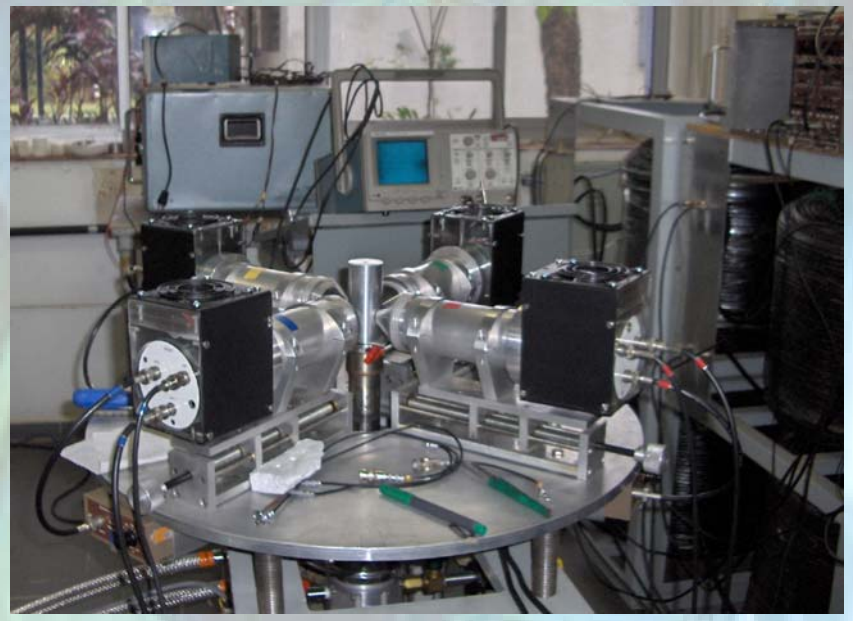
elastically bent silicon single crystal
focusing monochromator.

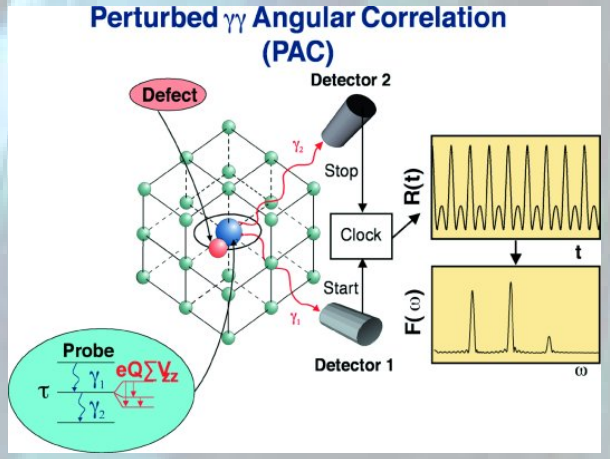
position sensitive detectors (PSD)

rotating oscillating collimator

Nuclear Hyperfine Interactions

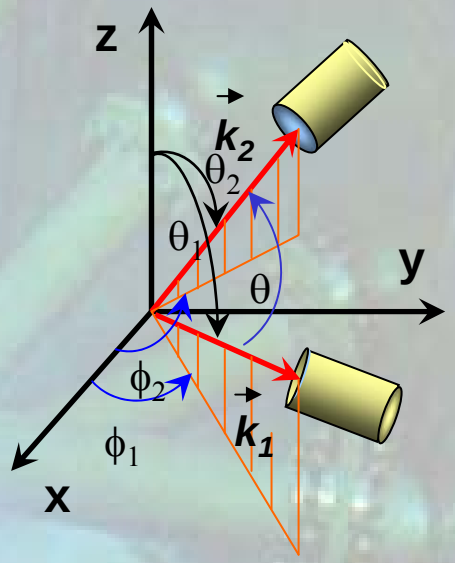
perturbed $\gamma\gamma$-angular correlation (PAC) using radioactive nuclear probes to study hyperfine interactions in solids





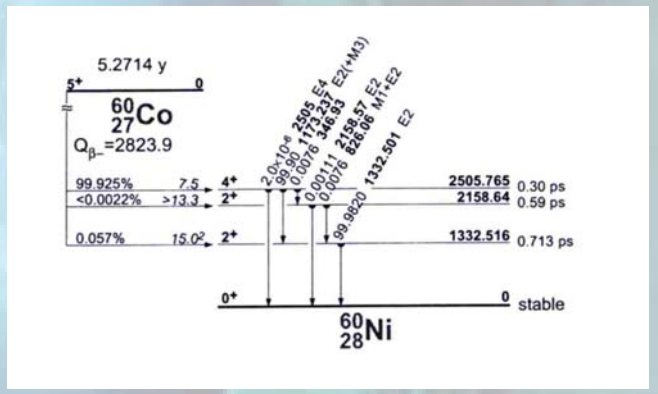
Electronic and Magnetic Properties of materials

Nuclear Structure Studies



γ-γ Angular correlation

High resolution gamma spectroscopy: γ-γ and β-γ angular correlation measurements following Radioactive decay of nuclei



Nuclear Decay Schemes

Most of the R&D programs have strong ties to universities, other national research institutes and laboratories.

CRPq takes its role very seriously as one of the major research reactor facility in the country providing educational opportunities to students in their programs related to nuclear sciences.

A large part of the research work has active participation of many graduate students, affiliated to the Reactor Center, working for their M.Sc. and Ph.D. degrees as well as some undergraduate students initiating scientific research.

Academic Activity

Students:

Ph.D. Program	20
M.Sc. Program	21
Post-Doc	04
Under-graduate	21
Total	66

14 courses are offered by the CRPq staff members in the post-graduate program of IPEN every year.

Scientific Production (2005-2006)

Publications:

Scientific Journals (Refereed)	77
Conference Proceedings (full Papers)	103

Conference Contributions:

International	31
National	43
Workshops	04

Theses concluded:

M.Sc.	09
Ph.D.	06

(Research Reactor Center)
Budget-(2006)

- Government funds:
  - Reactor Operation — US$ 50.000
  - Reactor Modernization — US$ 250.000
  - Research Program — US$ 35.000

- Extraordinary funds:*
  - Reactor Modernization — US$ 450.000
  - (*Electronuclear)

- IAEA -TC Project:
  - Reactor Modernization — US$ 123.000

- Research Grants:
  - (FAPESP, CNPq, IAEA, CAPES) — US$ 200.000

Total **US$1.108.000**

Some of the products and services offered by our center find their way to:

- ✓ petroleum industry,
- ✓aeronautical and space industry,
- ✓medical clinics and hospitals,
- ✓semiconductor industry,
- ✓environmental agencies,
- ✓universities and research institutions.

We produce special radioisotopes such as:

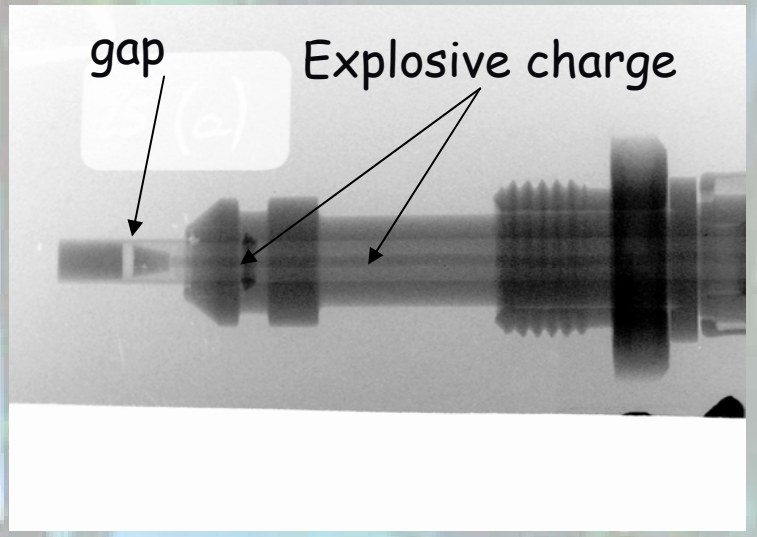
^{41}Ar and ^{82}Br for industrial process inspection, ^{192}Ir and ^{198}Au radiation sources used for brachytherapy, ^{153}Sm(EDTMP) for pain palliation in bone metastases, calibrated gamma sources of ^{133}Ba, ^{137}Cs, ^{57}Co, ^{60}Co, ^{241}Am and ^{152}Eu for clinics and hospitals practicing nuclear medicine and research laboratories

We offer regular services of nondestructive testing by real-time neutron radiography, multi-element trace analysis by NAA, neutron irradiation of silicon crystals for doping with phosphorus and miscellaneous neutron irradiation

Real time neutron radiography

Brazilian currency note

finger print



Pyrotechnic device

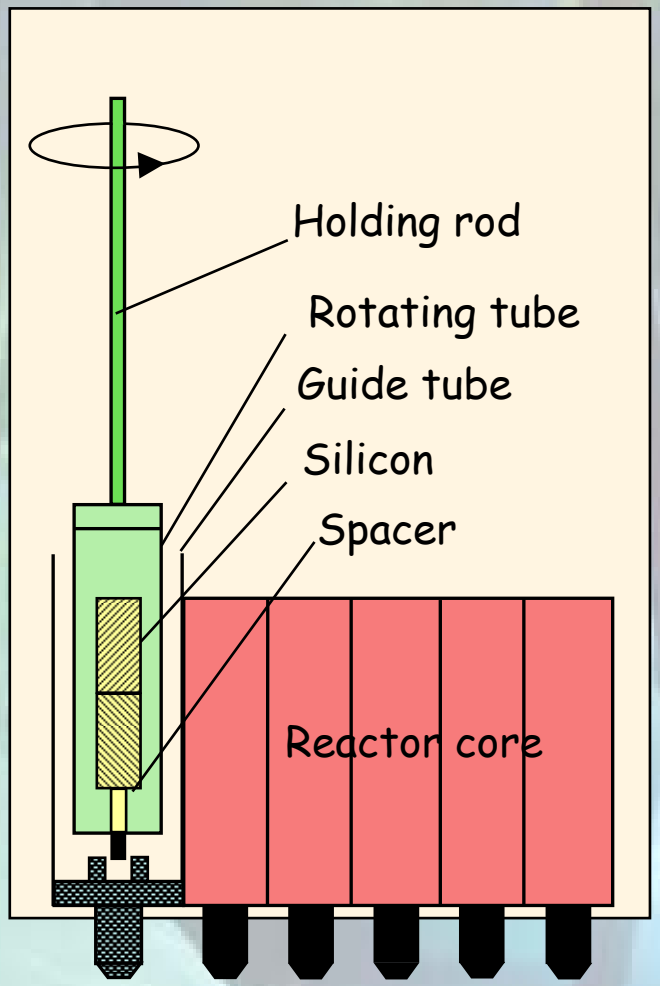
Neutron Activation Analysis

neutron activation analysis is applied to the fields of health, nutrition, agriculture, environment, geology and industry.

Nuclear and neutron Metrology

The laboratory produces and commercializes calibrated radioactive sources for use in industry, hospitals and clinics.

Silicon Irradiation



Silicon Irradiation Rig

Crystal diameter:	5 inch
Crystal length:	50cm
Target Resitivity:	30 Ohm.cm
Annual Capacity:	1200kg

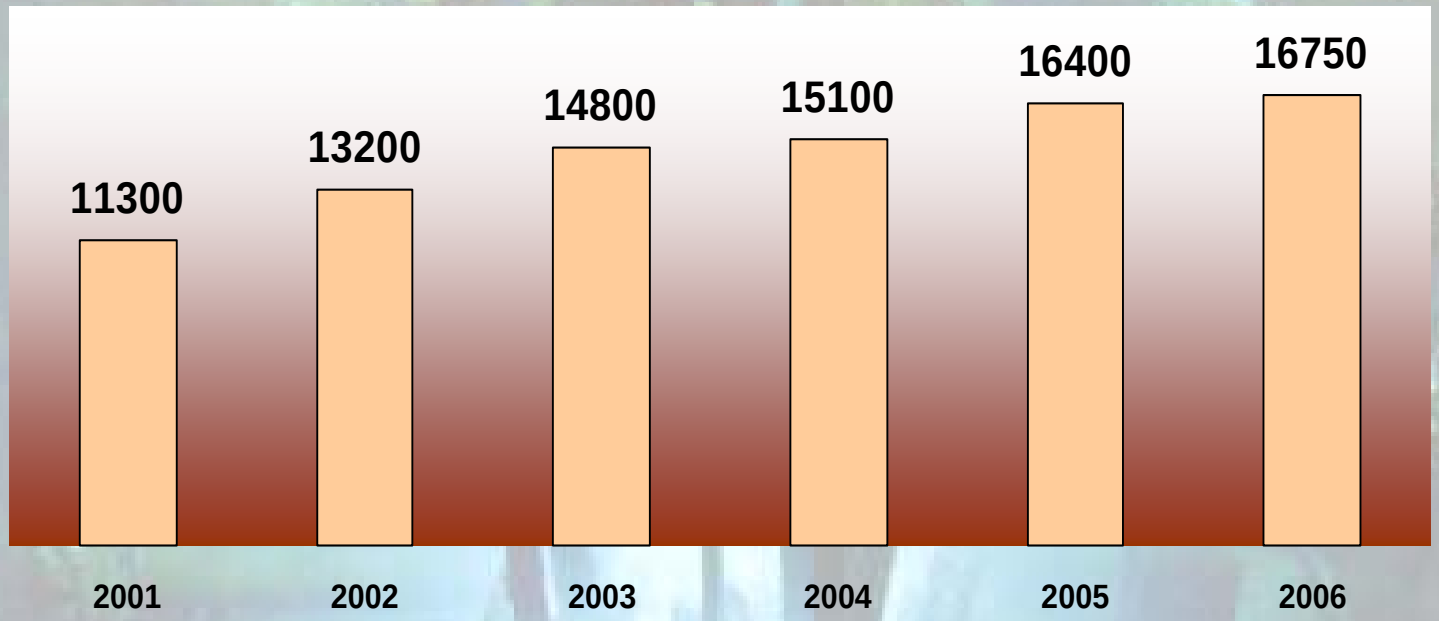
Radioisotope production at IPEN

In the early sixties IPEN started producing ^{131}I and several other radioisotopes such as ^{32}P, ^{198}Au, ^{24}Na, ^{35}S, and ^{51}Cr as well labeled compounds for medical use

Due to increasing demand these radioisotopes started to be imported which were then processed and distributed to the local medical centers.

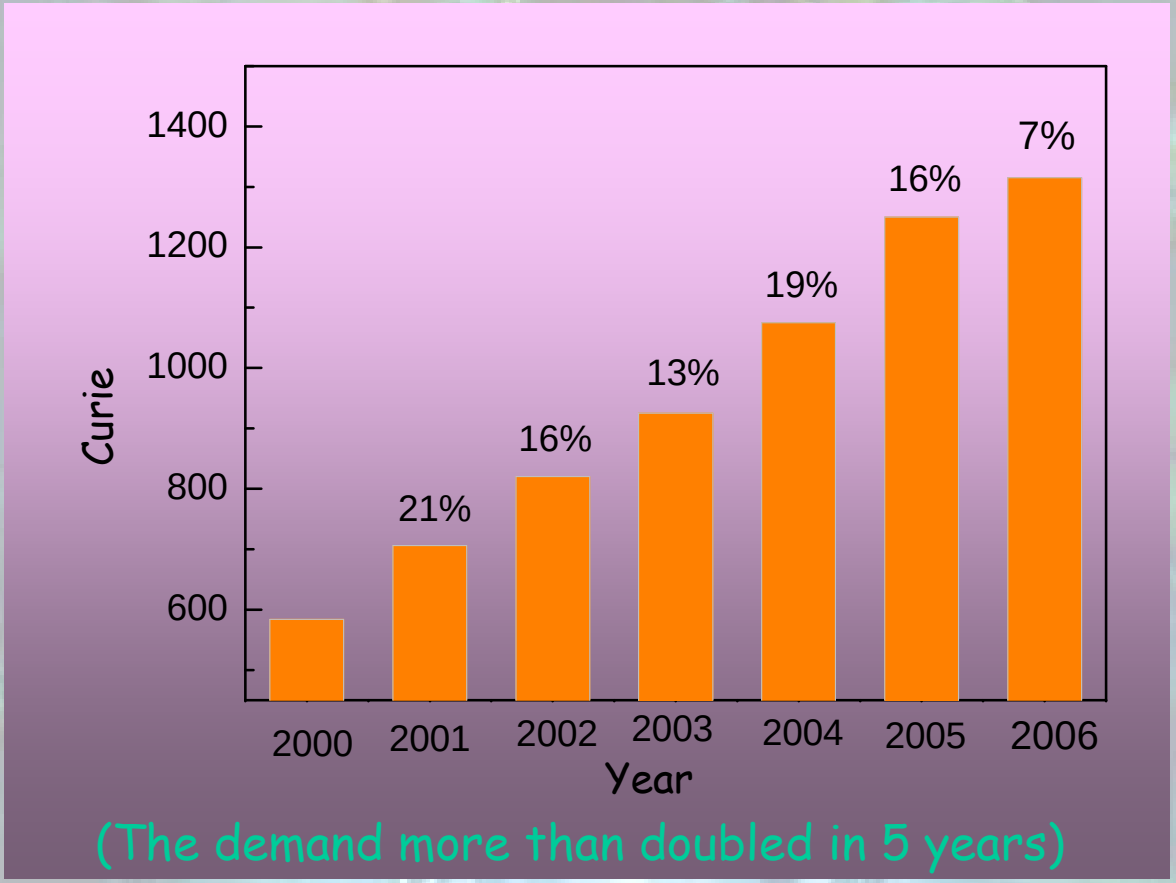
Since 1980 IPEN produces ^{99}Mo-^{99m}Tc generator kits from the fission ^{99}Mo imported from Canada

Number of ^{99m}Tc generators produced and commercialized



^{99m}Tc generators with individual kit activities between 250mCi and 2000mCi are produced and distributed to more than 260 hospitals and clinics throughout the country, benefiting more than 2.500.000 patients

^{131}I (Solution form)



(The demand more than doubled in 5 years)

More than 350 Ci Of ^{131}I in the form of capsules were also produced and distributed in 2006. Demand for this product is increasing at a rate of more than 20% each year

In addition to ^{99m}Tc generators, IPEN also produces and distributes radiopharmaceuticals based on ^{131}I (1700Ci), ^{51}Cr(1Ci), ^{32}P(3Ci), ^{153}Sm(36Ci), and sealed sources of ^{125}I and ^{192}Ir seeds for Braquetherary

sealed ^{192}Ir (12000Ci) sources are produced for industrial gammagraphy (all figures of 2006)

The reactor produced radioisotopes and some of the cyclotron produced radioisotopes such as ^{67}Ga, ^{201}Tl and ^{18}F used in nuclear medicine amount to receipts, from sales of the order of

24 million US$

Radioisotopes produced with IEA-R1 Reactor

^{131}I ~ 25Ci per week (70% of the demand)

^{153}Sm and ^{192}Ir (for Braquetherapy) 100% of demand

Viable commercial production of ^{99}Mo will start as soon as the power of the reactor is raised to 5MW


Reactor modernization
program

The reactor is ISO-9001:2000 certified since 2002 for the scope

"Reactor operation and irradiation services"

During the last several years a concerted effort was made to refurbish the old components and systems of the reactor, particularly those related with the reactor safety improvement, in order to upgrade the reactor power

Primary Objective was to enhance the utilization of IEA-R1 research reactor to produce primary radioisotopes, such as ^{99}Mo and ^{131}I, among several others, used in nuclear medicine in Brazil, by operating the reactor at 5 MW on a schedule of 120 hours/week continuous operation

Some of the recent implementations

✓New water treatment and purification system-2004/2005

✓Replacement of reactor control and safety rods-2004/2005

✓New primary heat exchanger-2006/2007

✓Installation of a new rabbit system for short irradiations in the reactor core-2007

✓Replacement of several radiation monitor and detectors-2006/2007

✓Pneumatic system to transfer reactor irradiated targets to processing area-2007

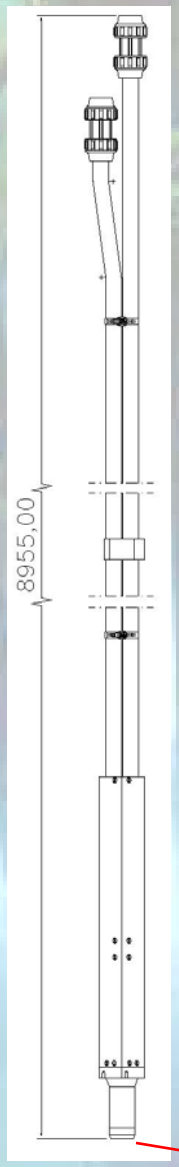
New reactor pool water treatment system

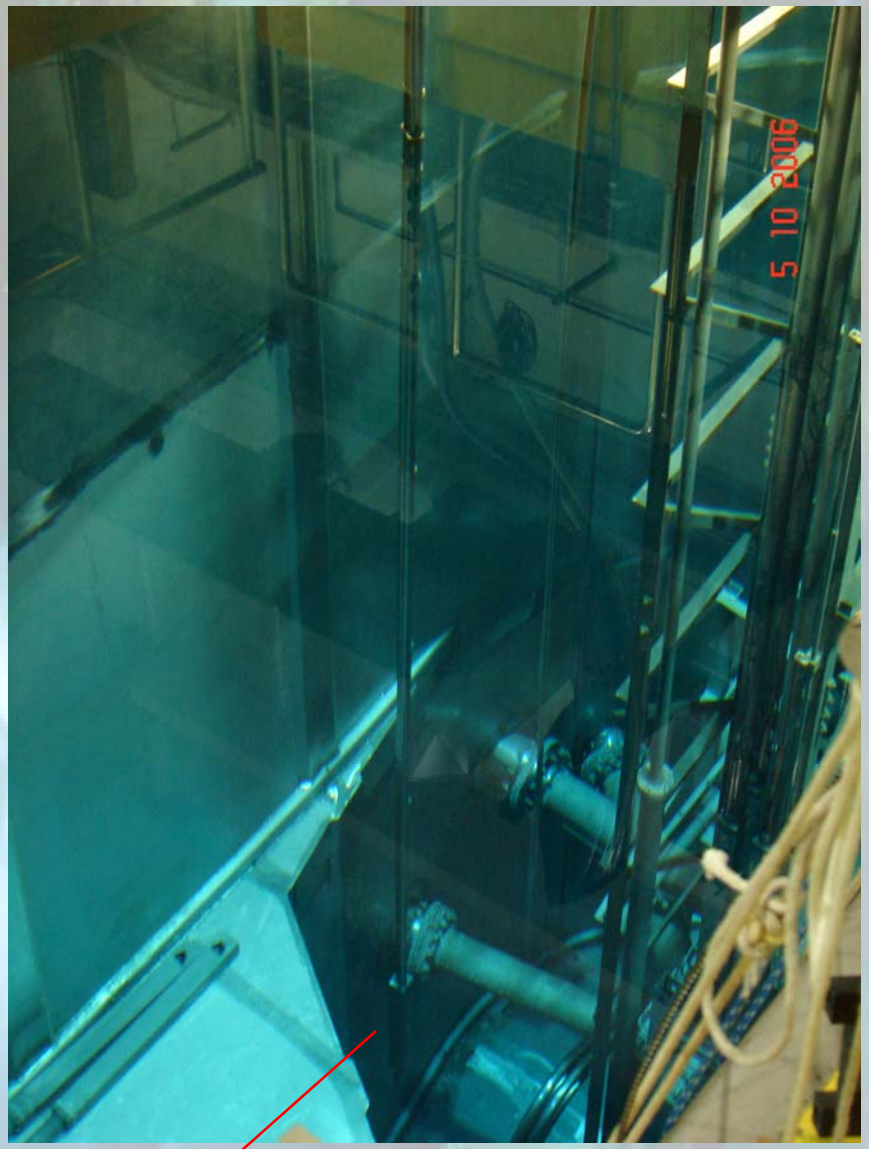
New controle rods (Cd+In+Ag) fabricated at IPEN

Pneumatic Irradiation system Constructed at IPEN

Rabbit station

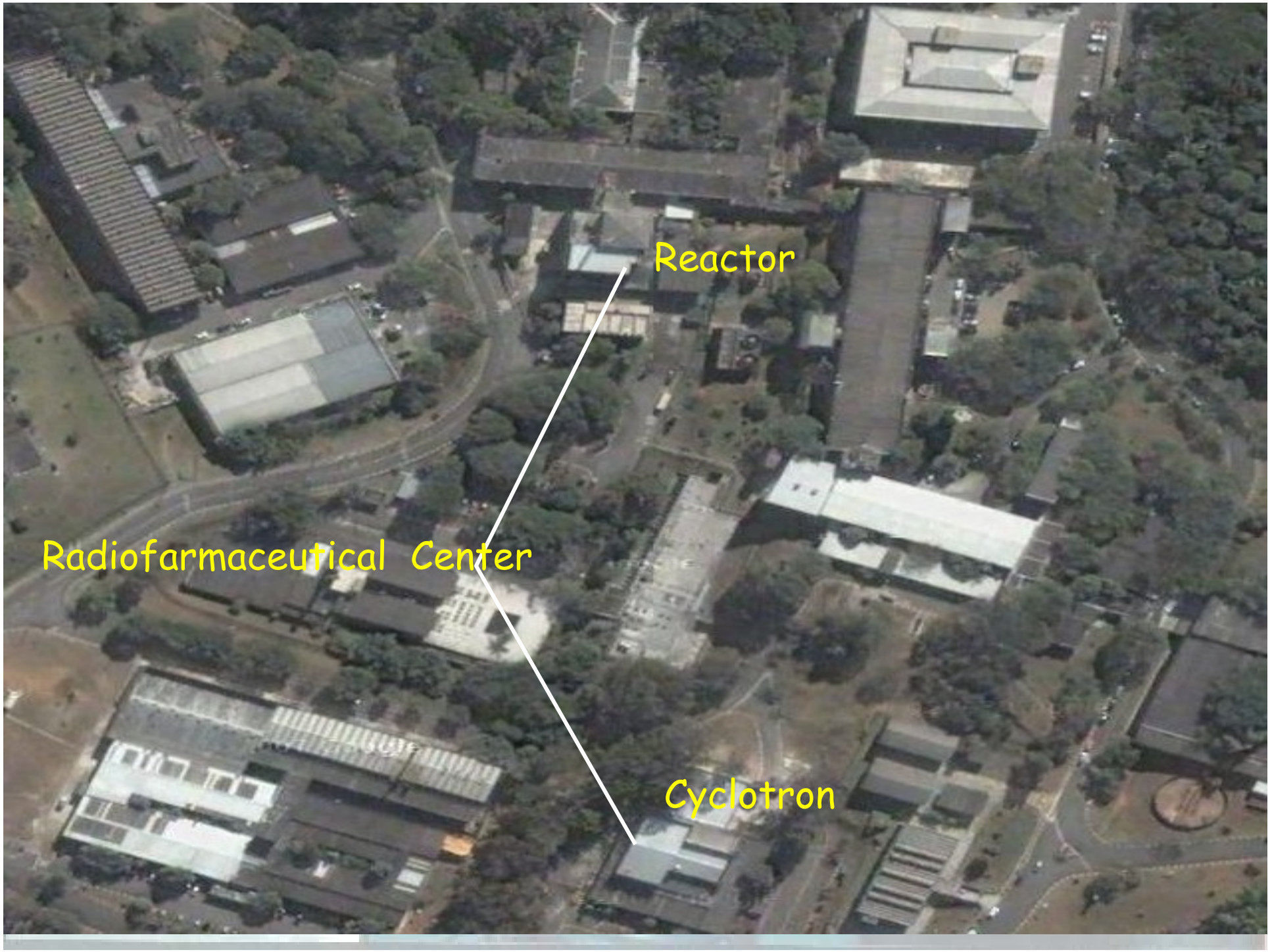
Control system





Irradiation device

The New Heat exchanger being Installed


Reactor
Radiofarmaceutical Center
Cyclotron

SISTEMA DE CORREIO PNEUMÁTICO

cnen Comissão Nacional de Energia Nuclear — Instituto de Pesquisas Energéticas e Nucleares ipen

LAYOUT

LEGENDA

1 IODO RECUPERAÇÃO (Recebe do reator)
2 CORTE DE CAPSULA (Recebe do reator)
3 IODO VIA SECA (Recebe do reator)
4 IODO VIA SECA (Recebe do reator)
5 GALIO (Recebe do ciclotron)
6 TALIO (Recebe do ciclotron)
7 FLUOR (Recebe do ciclotron) - Futuro
8 FLUOR (Recebe do ciclotron) - Futuro

A LINHA DE EMERGÊNCIA REATOR/RADIOFARMACOS
B LINHA DE EMERGÊNCIA REATOR/CAVERNA
C LINHA DE EMERGÊNCIA CICLOTRON/RADIOFARMACOS
D LINHA DE EMERGÊNCIA CICLOTRON/CICLOTRON (SALA DE FONTES/HOT CELL

ESTAÇÃO TUBULAR LINHA PRINCIPAL
ESTAÇÃO TUBULAR LINHA DE EMERGÊNCIA
ESTAÇÃO TUBULAR LINHA DE RETORNO
PAINEL DE COMANDO DAS ESTAÇÕES DA LINHA PRINCIPAL AC3000
PAINEL DE COMANDO DAS ESTAÇÕES DA LINHA DE EMERGÊNCIA AC2
SINALIZAÇÃO REMOTA SONORA LUMINOSA DE TODAS AS ESTAÇÕES
VÁLVULA SLIDE GATE PARA FRENAGEM PNEUMÁTICA DAS ESTAÇÕES DA LINHA DE EMERGÊNCIA
PAINEL DE COMANDO DOS COMPRESSORES 380/440V
DERIVADOR AC3000 DE 4VIAS
DERIVADOR AC3000 DE 3 VIAS
DERIVADOR AC3000 DE 2 VIAS
FILTRO HEPA (Fornecido pelo IPEN)
COMPRESSOR RADIAL TRIFÁSICO CR-8 380/440V LINHA PRINCIPAL
COMPRESSOR RADIAL TRIFÁCIO CR-8 380/440V LINHA DE EMERGÊNCIA
DISPOSITIVO AUTOMÁTICO PARA REVERSÃO DE CÁPSULAS
ESTAÇÃO AUTOMÁTICA AC3000 UT LINHA PRINCIPAL DOTADA DE SENHA
PAINEL DE COMANDO DAS ESTAÇÕES UT AC3000 COM SENHA
TUBULAÇÃO DE PEAD 125MM PARA ENVELOPE DA TUBULAÇÃO DE PVC LINHA PRINCIPAL
TUBULAÇÃO DE PEAD 125MM PARA ENVELOPE DA TUBULAÇÃO DE PVC DA LINHA DE EMERGÊNCIA
TUBO DE PVC DA LINHA PRINCIPAL
TUBO DE PVC DA LINHA DE EMERGÊNCIA

REATOR

PAINEL DE COMANDO

DERIVADOR DE POSIÇÕES

RADIOFARMACOS

ALA QUENTE
ALA QUENTE 2
LAB 1 AS 16
LAB 3 AS 14
LAB 5 AS 38
LAB 7 AS 40
PORÃO
C
A
B
FOSSO
CAVERNA
COMPRESSOR RADIAL CR-8
HOT CELL

SINALIZADOR

CYCLOTRON

FILTRO ABSOLUTO
COMPRESSOR RADIAL CR-8
SALA DE FONTES HOT CELL

DISPOSITIVO DE FRENAGEM

COMPRESSOR RADIAL

Other infrastructure improvement

Modernization of reactor fuel element
Fabrication facility to upgrade the production capacity to 15-18 U_3Si_2 (3.0 g/cm^3) type fuel elements per year

Optimization of radiochemical facilities to process ^{99}Mo using gel-process

Implantation of an effective project for spent fuel management and storage

(prototype of a storage cask under construction)

IAEA-Technical cooperation Project BRA/04/0506

"Modernization of the IEA-R1 research reactor to secure safe and sustainable operation for radioisotopes production"

Project concluded on 31/12/2006

Funds Aproved by IAEA (US$)

	(2005)	(2006)	Total
Experts(E)	14,000	14,000	28,000
Fellowships(FE)	13,000	13,000	26,000
Scient.Visits(SV)	25,000	25,000	50,000
Equipment(EQ)	60,000	70,000	130,000

Total: 234,000

Funds Effectively Used (US$)

Equipment(EQ)	178,000
Experts (2), FE (8), SV (4)	62,000

Total 240,000

Equipament recieved from AIEA

GM and NAI(Tl) detectors

Swipe Detector

Contamination Monitor

Portal Personnel Monitor

Portable Neutron Detector

Continuous Vibration Monitoring System

Lead Glass Window for Hot Cell

Work station for Neurtonic and thermal hydraulic Calculations

Self-Powered detector for Neutron flux Measurements

Ionization Chambers

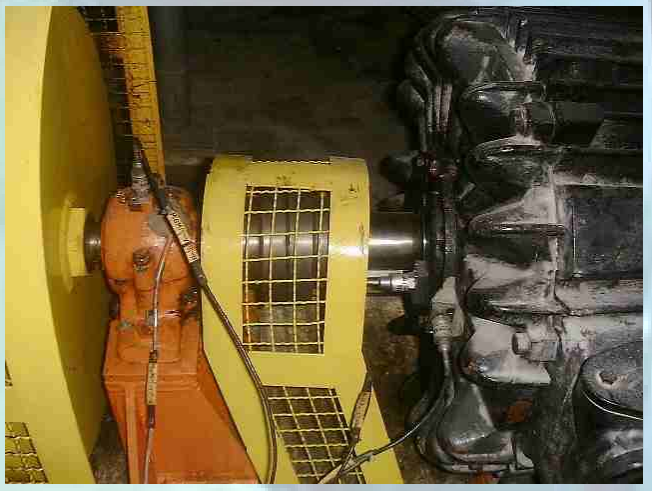

Inspection and Monitoring
programs

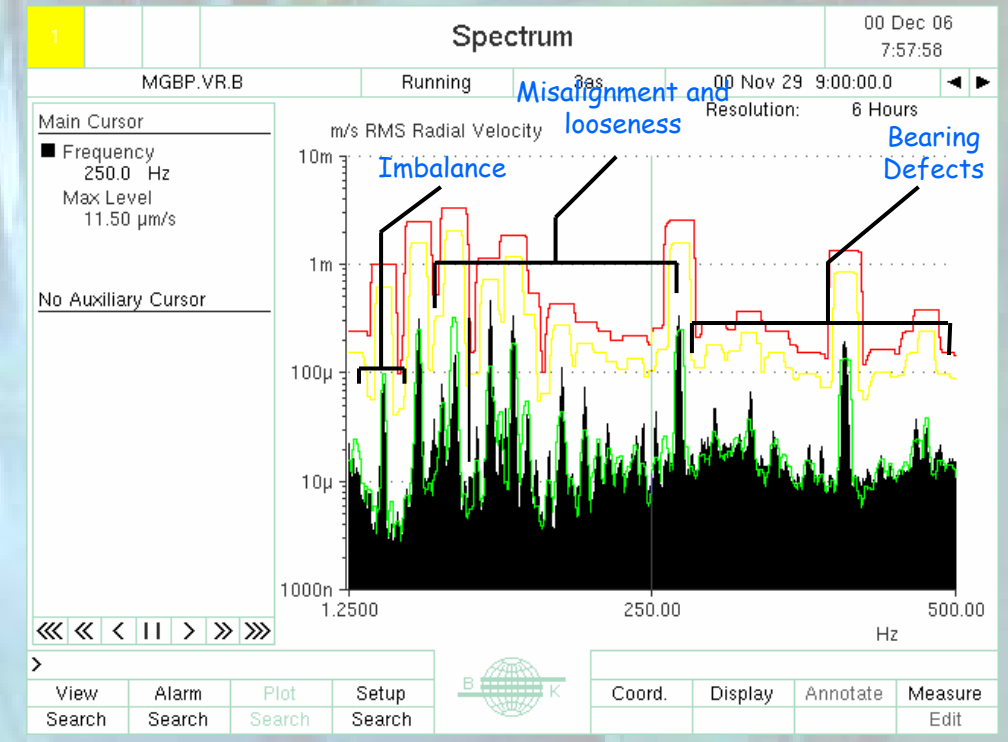
Continuous Vibration Monitoring System (CVMS)

The rotating machinery in the IEA-R1 reactor system is primarily the water circulating pumps. A continuous vibration monitoring system has been installed.

This will provide accelerometer data to a central processing unit that will monitor the changes in the vibration levels of the pump-motor system.

Defects such as imbalance, misalignment, looseness, and bearing faults can be detected before a catastrophic failure occurs. Thus, incipient fault detection and diagnosis of rotating machinery is an important feature of this upgrade.

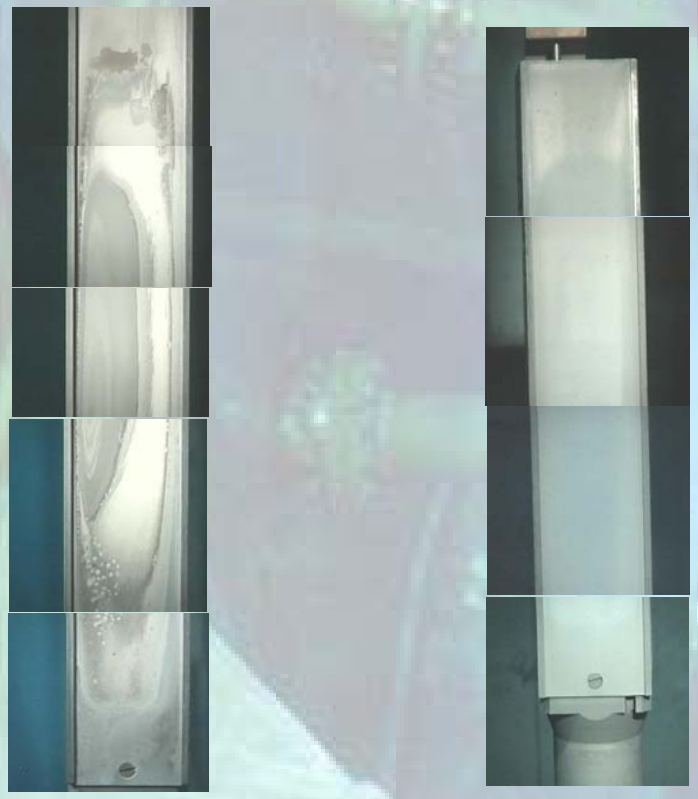




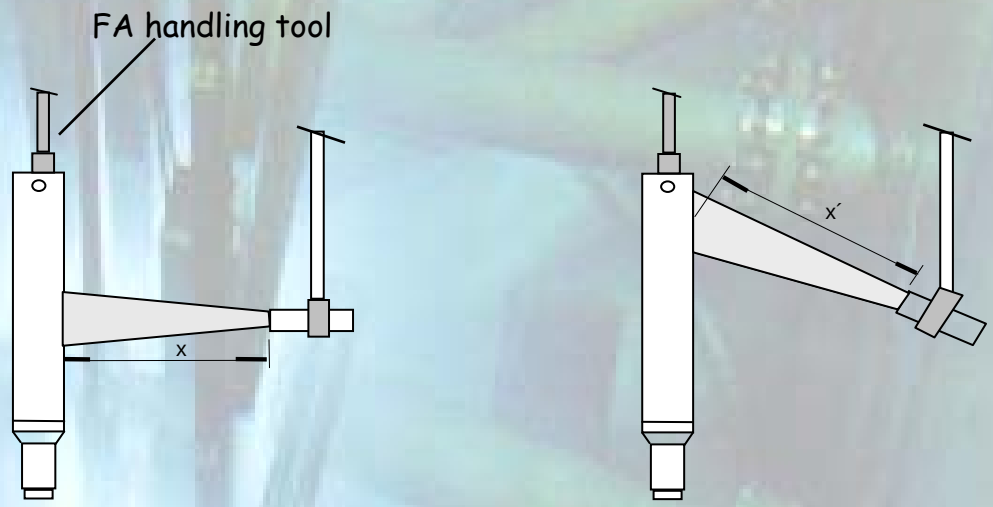
Example of Vibration Monitoring of Rotating Machinery

Visual Inspection of Fuel Elements

Underwater camera is used to inspect fuel elements to detect signs of oxidation or corrosion of fuel plates



Images of fuel elements



Under Water Camera

Sipping test

Sipping analysis is performed if there is an indication of fission product release in the pool water

The suspected fuel element is enclosed in an aluminum tube and water is percolated through it for several hours

A sample of this water is collected and analyzed by high resolution gamma spectroscopy using HPGe detector to detect fission product nuclides

Safety Culture Enhancement and ALARA Programs Under Implantation

Conclusions/ Lessons Learned

✓Our experience has shown that the modernization and refurbishment program in small research reactors must be a continuous activity

✓Small steps should be taken to improve the performance of the reactor with small budgets and shorter shut down periods rather than very extensive refurbishment programs requiring large sums and long shutdown times

✓In both cases however a very well planned and skilful management of these activities are required

✓Development of a strategic plan for the effective utilization of the research reactor is an essential step

✓Continuous efforts should be made to maintain the reactor utilization index as high as possible

✓Implantation of an integrated management system including quality assurance, safety culture and environmental consciousness is essential for reactor operation, maintenance and irradiation services

✓This can help a great deal in elevating the self esteem and a sense of collective responsibility in the reactor staff.

✓This ultimately reduces the necessity of unplanned maintenances and refurbishments in the reactor systems and components.

✓Planning, efficient management and continuous improvement are key words in a quality management system.

✓The production of radioisotopes for medical and industrial application is essential but reactor utilization in academic and applied research and education are equally important particularly in developing countries


Thank you for your kind attention