



STATUS OF THE R&D ACTIVITIES ON
FAST REACTORS AND ACCELERATORS
DRIVEN SYSTEM IN BRAZIL

TWG-FR-ADS

22- 26 April 2002

Karlsruhe,
Germany

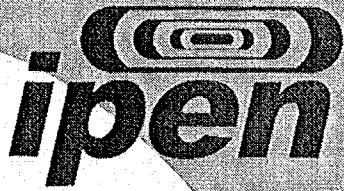
by

J.R.MAIORINO

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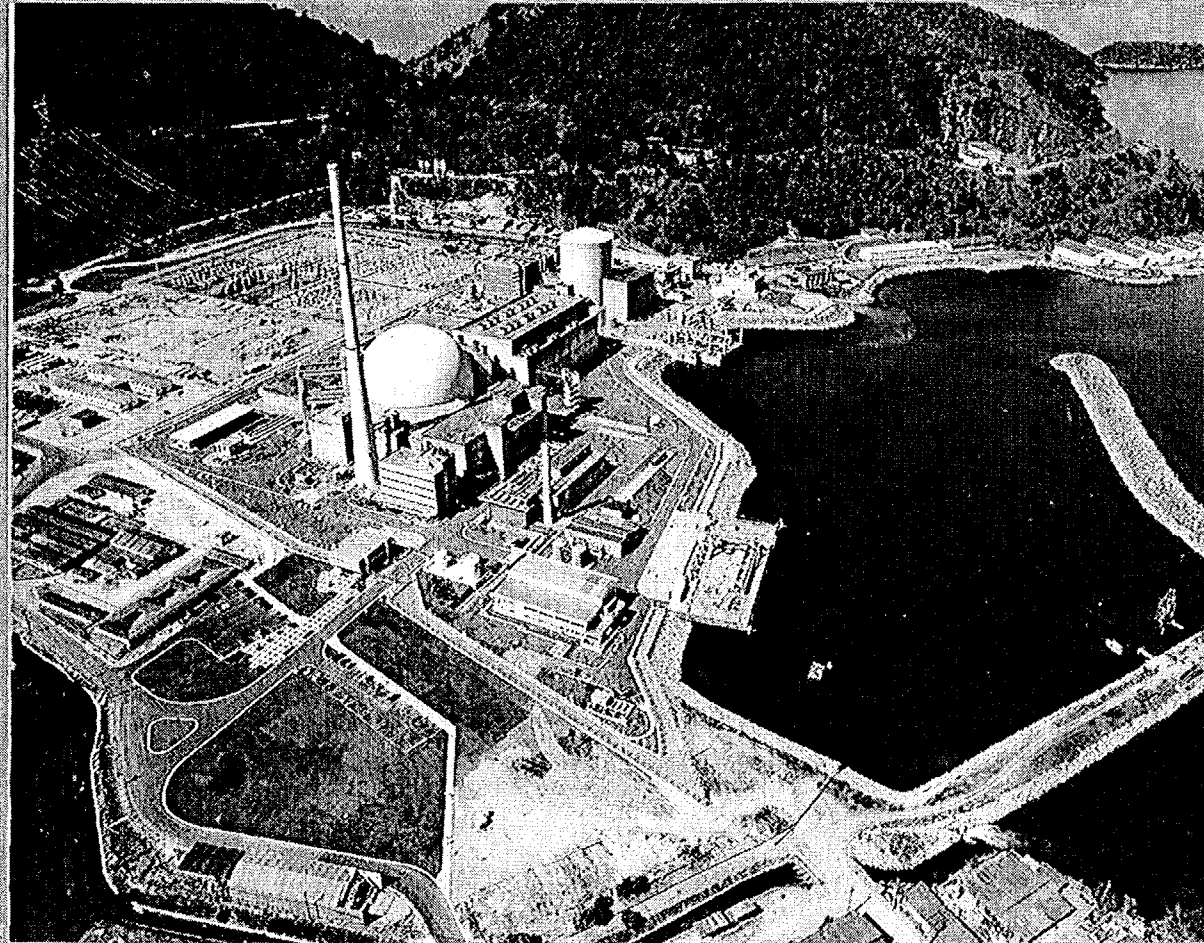


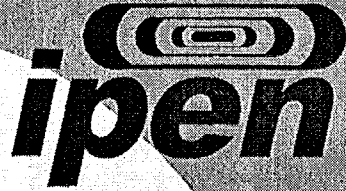
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Nuclear Energy in Brazil is generated by 2 LWR, ANGRA I, a Westinghouse 657 MW, and ANGRA III, a SIEMENS, 1309(1350) MW. A third unit is under construction (ELETRONUCLEAR)

The total electric power installed in Brazil, is 69 GW(300 TWh), being ~ 2% Nuclear. During 2001 Brazil had an Energy Crises, and Nuclear gave a big contribution to minimize it, mainly in the south east





Nuclear Sector in Brazil

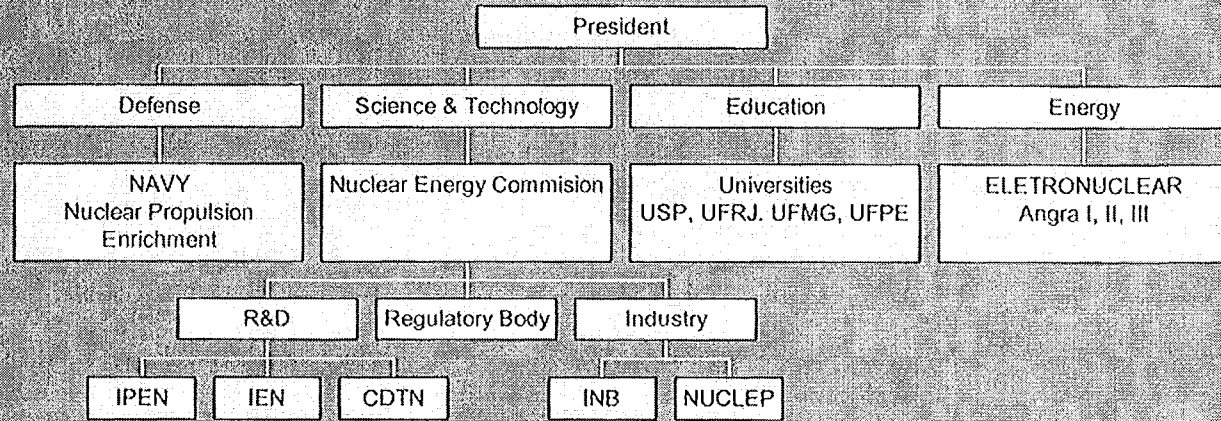
Advanced Reactor
Forum

<http://extranet.cnen.gov.br/fra/>

•GIF-generation iv(WR; FR)

•IAEA- TWR-FR-ADS; INPRO

•IRIS: International Reactor Innovative & Secure



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IAEA-TWG-FR

Karlsruhe
April 2002

NEWS- EVOLUTION, ADVANCED REACTOR FORUM AND A
PROPOSAL OF A PROGRAM FOR ACCELERATOR APPLICATION

INTRODUCTION

Fast Reactors and ADS Research

- 70
- R&D activities in Brazil start in the 60 at IEN in cooperation with TECHNICATOME .In 1972 a small(100 kW) Sodium was constructed(AGHINA)
 - .At IPEN Research on GCFBR in Cooperation with GA were conducted .A He Loop was constructed and a Critical Assembly (ZPR) Split Table was designed-Th Fuel Motivation(1972-1975)
 - At IEN an agreement with ANSALDO-NIRA results in an acquisition of a Na Loop for Termal hydraulicsStudies was made However it was never assembled (1981)
 - In 1979 at IEAV a Research group was formed .A concept of a Binary Breeder Reactor using two cycles Th and U in Reactor Core(ISHIGURO-1984)
 - During the 90'a National Program(IPEN,IEN,ITA,IPT) to conduct R&D(pyroprocess , ,U-Zr Metallic Fuel ,HT-9 , ElectromagneticPump ,and a conceptual Design of a Experimental Reactor(60/20 MWth/Mwe)) was proposed (NASCIMENTO,1994) .However this program was closed in 1999 .
 - Nowdays only academic research are being conducted at IPEN and they will be described in this meeting .Basically they are :
 - 1.An Integral Lead Reactor Concept for DevelopingCountries
 2. Alternative Concept for a Fast Energy Amplifier Accelerator Driven Reactor



An Integral Metallic-Fueled and Lead-Cooled Reactor Concept (ILR)

Adimir dosSantos and Jamil A. Nascimento

ABSTRACT

An Integral Lead Reactor (ILR) concept is proposed for the 4th generation reactor to be used in the future. The ILR is loaded with metallic fuel and cooled by lead. It was evaluated in the 300-1500 MWe power range with the Japanese Fast Set 2 cross sections library. This set was tested against several fast benchmarks and the criticality uncertainty was found to be 0.51 % Δk . The reactor is started with U-Zr and changes to the U-TRU-Zr-RE fuel in a stepwise way. In the equilibrium cycle, the burnup reactivity is less than β_{eff} for a core of the order of 300 MWe, pin diameter of 10.4 mm and a pin-pitch to diameter ratio of 1.308. The lead void reactivity is negative for reactor power less than 750 MWe. There is a need to improve the nuclear data for the major actinides.

Note: Presented at Nuclear Data Conference held at Tsukuba, Japan, 2001. Also accepted for publication at Journal of Nuclear Science and Technology



ILR Model and Calculation Methodologies I

- Core Height=100 cm
- Structural Material= HT-9
- Inlet T.=420 C
- Outlet T= 540 C
- $q' = 200 \text{ W/cm}$

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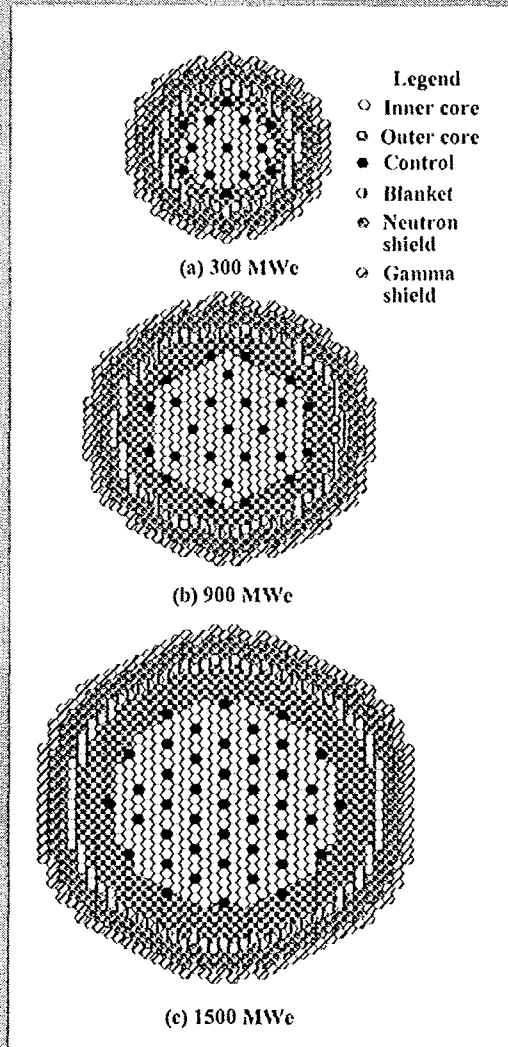


Table 2 ILR RZ core model characteristics

Power (MWe)	300	900	1500
Inner core radius (cm)	93-168	159-288	204-370
Outer Core radius (cm)	107-195	173-315	218-395
Blanket radius (cm)	136-247	202-367	246-446
Shield radius (cm)	150-273	216-392	270-471
Vol. fraction (%), prod. =	1.308	1.417	1.495
Fuel	32.6	28.1	25.3
Structure	20.4	18.2	16.8
Coolant	47.0	53.7	57.9

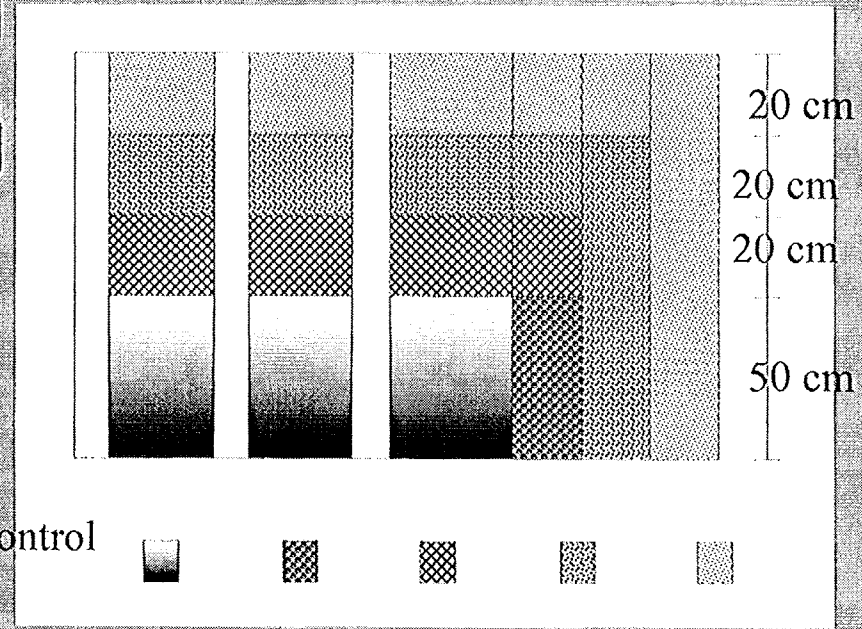
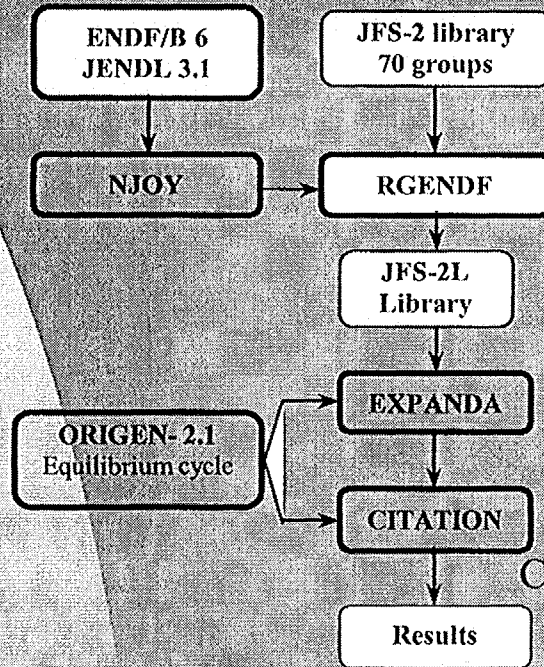
Power (MWe)	300	900	1500
	# Assemblies		
Inner core	66	204	342
Outer core	60	180	288
Control	13	25	43
Blanket	48	78	96
Neutron shield	114	174	210
Gamma shield	66	96	114



ILR Model and Calculation Methodology II

The ILR start with U-Zr, and changed to U-TRU-Zr-RE. The ILR BU is 100 MWd/kg, and the core reloading was performed in three batches. The burn-up reactivity is:

$$\Delta k_{Bu} = \Delta k_{Swell} + \Delta k_{Transm}$$



Core Blanket Lead B4C HT-9

ILR two-dimension (RZ) cylindrical model



ILR Model and Calculation Methodology III

The Calculation strategy is based on interactive of EXPANDA, CITATION and ORIGEN. Two enrichments, *in-out*, were adjusted to flat power distribution, using the criteria that the reactor must be critical at EOC. Then the core was burned using cross section obtained at the BOL and the chains shows in Fig. 3 . ORIGEN performs the approach to the equilibrium cycle starting from the first cycle. The average fuel calculation for the EXPANDA-CITATION equilibrium analysis is show in table 3.

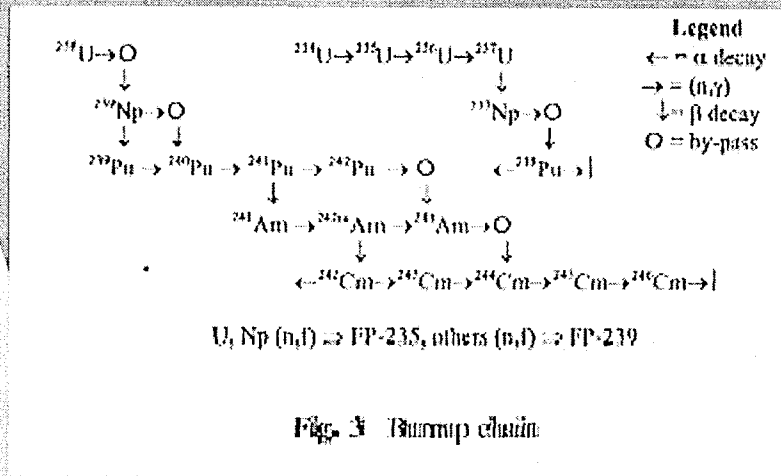


Fig. 3 Burnup chain

Table 3 ILR equilibrium fuel composition.

Nuclide	(w/o)	Nuclide	(w/o)	Nuclide	(w/o)
²³⁷ Np	1.79	²⁴² Pu	1.95	²⁴¹ Cm	0.01
²³⁸ Pu	2.49	²⁴¹ Am	2.22	²⁴⁴ Cm	0.23
²³⁹ Pu	57.12	^{242m} Am	0.10	²⁴⁵ Cm	0.06
²⁴⁰ Pu	30.05	²⁴³ Am	0.65	²⁴⁶ Cm	0.01
²⁴¹ Pu	3.32	²⁴² Cm	0.01		

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RESULTS AND DISCUSSION I

The main requirement for the ILR is to have

$$\Delta k_{Bu} < \beta_{eff}$$

to mitigate TOP accident. The TOP reactivity is given by:

$$Prop = \frac{\Delta k_{Bu}}{\text{number of control assembly}} \quad (2)$$

Table 4 ILR first and equilibrium cycle results

Power (MW _e)		300	900	900	1500
Min. (mm)	6.35	6.35	10.4	10.4	10.4
P/D ratio	1.308	1.495	1.308	1.308	1.308
First Cycle					
E_{in} (w/c)	16.8	18.8	14.2	13.1	13.1
E_{out} (w/c)	28.2	31.4	20.8	16.5	15.5
Δk_{Bu} (%)	-5.76	-6.07	-4.15	-2.78	-2.52
β_{eff} (10^{-4})	7.10	7.06	6.95	6.81	6.76
CR	0.41	0.36	0.55	0.65	0.68
Filencees(10^{23})	1.26	1.12	1.48	1.62	1.74
DC (10^{-4})	-2.47	-2.25	-3.09	-3.58	-3.70
Equilibrium Cycle					
E_{in} (w/c)	16.6	18.7	14.1	13.4	13.4
E_{out} (w/c)	25.4	28.6	19.1	16.1	15.2
Δk_{Bu} (%)	-3.39	-4.26	-0.64	+1.12	+1.51
β_{eff} (10^{-4})	3.81	3.61	3.92	3.91	3.91
CR	0.77	0.69	0.96	1.06	1.08
Filencees(10^{23})	1.51	1.34	1.82	2.07	2.39
DC (10^{-4})	-2.28	-2.16	-2.76	2.99	-3.07

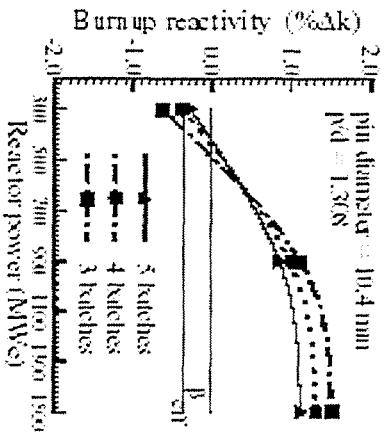


Fig. 4 Equilibrium cycle burnup reactivity versus reactor power and rodlengths batch/rod number

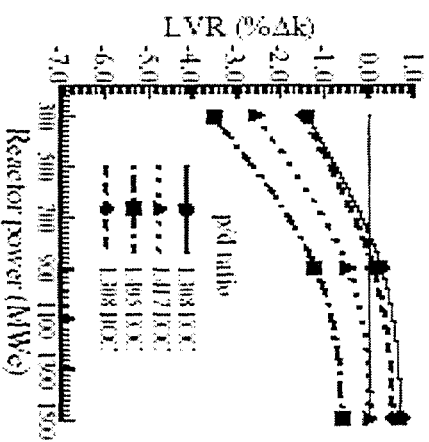


Fig. 5 End of equilibrium cycle rod w/d reactivity versus reactor power and p/d ratio for a pin diameter of 10.4 mm

An ILLR concept that satisfies many requirements of the 4th generation reactor is proposed. A key characteristic is that it may be a cleaner concept due the partition/transmutation scheme adopted. The initial enriched uranium must be substituted quickly by the generated TRUs to mitigate the TOP reactivity. In the equilibrium cycle, the TOP accident will be not a concern for reactor power of ~ 300 MWe, pin diameter of 10.4 mm and p/d ratio of 1.308 because Δk_{eff} is $< \beta_{\text{eff}}$. The ILLR must be optimized in respect to fast fluence to satisfy the present HF-9 limit of 4.0×10^{23} (n/cm²). The Doppler effect is small, as expected in fast reactors loaded with metallic fuel. The LVR is negative for reactor powers less than 750 MWe. The present nuclear data uncertainty must be improved, mainly for major actinides.



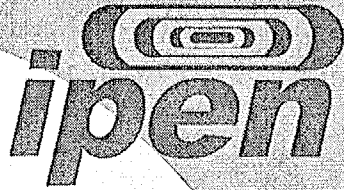
Na Alternative Concept for a Fast Energy Amplifier Accelerator Reactor

Studies

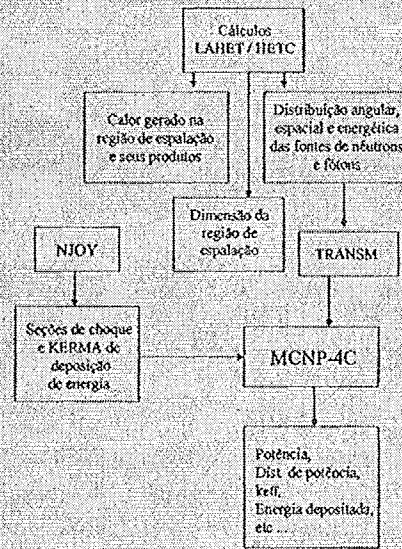
- Calculation Methodology
- Heating and Temperature Distribution
- Benchmarking
- BOL Conceptual Calculation
- Protactinium effect in Reactivity(Pa-233)

Motivation and Preliminary Remarks

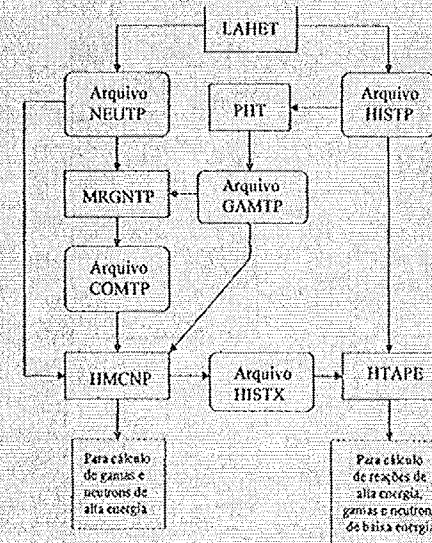
- To start in Brazil an R&D on ADS(motivated by Rubbia visit in Brazil in the late 90)
- Utilization of Th and Gas cooled Reactors(previous studies already existed)
- Alternative concept from Rubbia proposal includes more than 1 point of spallation to reduce Accelerator requirement, flat the power; Pb Solid cooled by He.
- Two lines: one using an hexagonal array of pins. and another using refueling on line similar of the CANDU. Both imbibed in a solid Pb cooled by He. These ideas had been reported in the TWG-FR 2001(Kazakhstan), and in conferences and papers



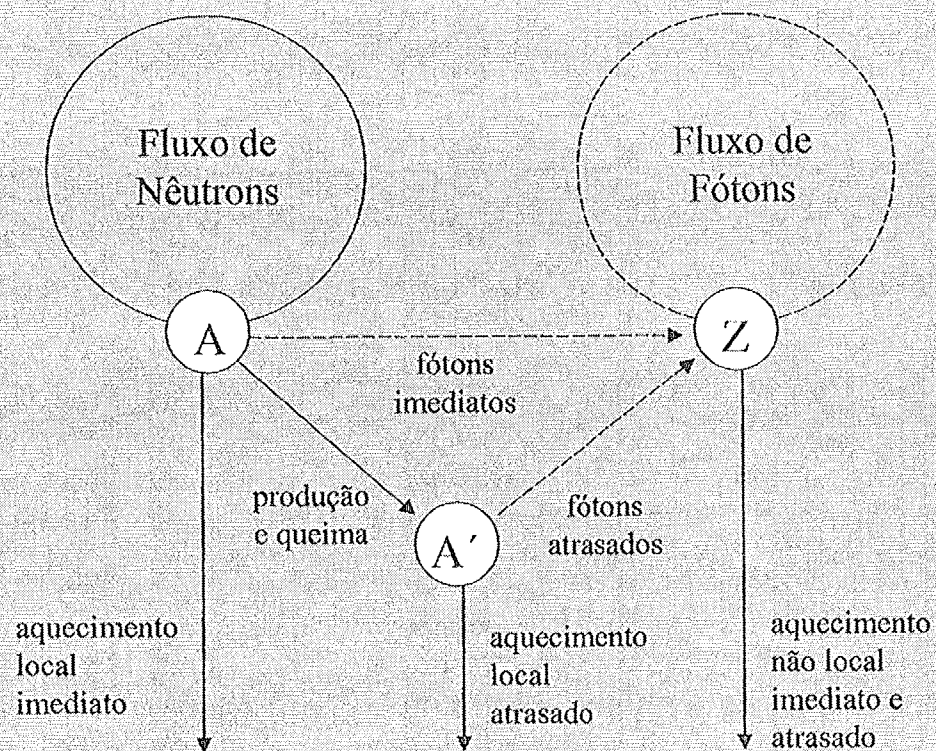
Calculation Methodology Codes



Calculation Methodology



LAHET CODE SYSTEM



VIII.3.2.2. AQUECIMENTO NUCLEAR, O MÓDULO HEATR

O aquecimento é um parâmetro importante em qualquer sistema nuclear. Ele pode representar o produto que está sendo vendido — como a potência do reator — ou ele pode afetar o projeto dos sistemas periféricos como os componentes de blindagem ou estruturais.

O aquecimento nuclear pode ser convenientemente dividido em aquecimento de nêutrons e aquecimento de gamas, como mostra a figura 7.4. O aquecimento devido a nêutrons em uma dada região é proporcional ao fluxo de nêutrons local e origina-se da interação dos nêutrons com a matéria (incluindo tanto as partículas secundárias carregadas como o recuo do próprio núcleo alvo). De modo similar, o aquecimento devido aos gamas é proporcional ao fluxo de gamas secundários transportados desde a região da prátia interna do nêutron que os geraram. Isto também é calculado devido à interação de gamas com a matéria (por exemplo, pares elétron-pósitron e o recuo induzido pela captura fotoelétrica).

O aquecimento, entretanto, é geralmente descrito pelos fatores de KERMA (*Kerma*, *Energy Release in Materials*) $k_{ij}(E)$ definidos de modo que a taxa de aquecimento em uma mistura seja dada por:

$$H(E) = \sum_i \sum_j \rho_i k_{ij}(E) \phi(E) \quad (9)$$

onde ρ_i é a densidade do material i , $k_{ij}(E)$ é o fator de kerma para o material i e a reação j partícula incidente com energia incidente E , e $\phi(E)$ é o fluxo escalar de nêutrons ou gamas para energia E . O KERMA é usado exatamente como uma seção de choque microscópica de reação exceto que a unidade é energia x seção de choque (eV-barns para o HEATR). O método direto para computar o fator kerma é:

$$k_{ij}(E) = \sum_l \bar{E}_{ijl}(E) \sigma_{ijl}(E) \quad (10)$$

onde a soma é realizada sobre todos os produtos da reação incluindo o recuo do núcleo, e E_{ijl} é a energia cinética total carregada pela l -ésima espécie da partícula secundária.

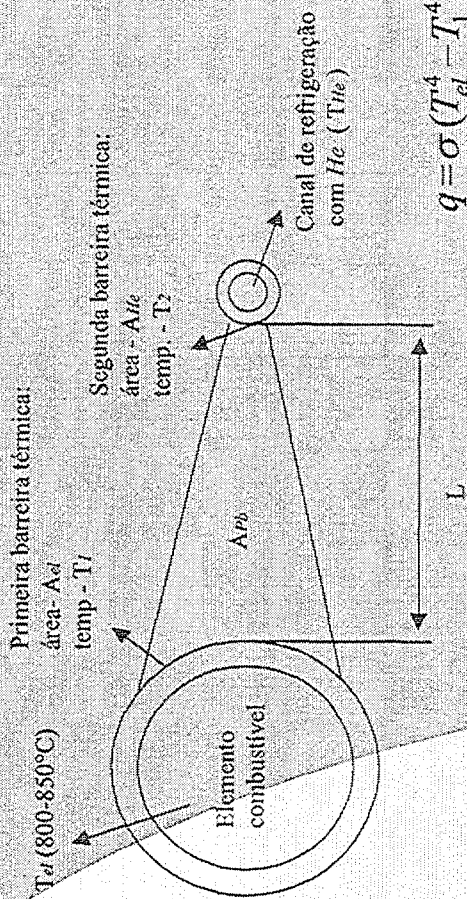
O sistema NJOY, através do módulo HEATR, calcula a maioria destes fatores de Kerma p “método de balanço de energia”. A energia atribuída aos nêutrons e gamas é simplesmente subtraída da energia disponível para obter a energia carregada pelas partículas carregadas:

$$k_{ij}(E) = (E + Q_{ij} - \bar{E}_{ijn} - \bar{E}_{ij\gamma}) \sigma_{ij}(E) \quad (11)$$

onde Q_{ij} é o valor da diferença de massa Q para a reação j , E_{ijn} é a energia total dos nêutrons secundários, incluindo a multiplicidade, e $E_{ij\gamma}$ é a energia dos gamas secundários, incluindo rendimento fotônico. Entretanto, a energia disponível deve ser calculada com um Q efetado por:

$$\bar{Q} = \frac{\sum_i \rho_i \sigma_i Q_i}{\sum_i \rho_i \sigma_i} \quad (12)$$

onde ρ_i é a fração atômica do isótopo i no elemento. Este número depende da energia e p ser representado apenas aproximadamente pela constante Q disponível no ENDF/B.



$$q = \sigma (T_{el}^4 - T_1^4) A_{el} \quad \text{Radiação}$$

$$q = k_{pb} \frac{T_1 - T_2}{L} A_{pb} \quad \text{Condução}$$

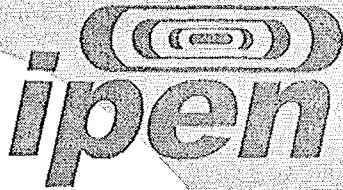
$$q = h(T_2 - T_{He}) A_{He} \quad \text{Convecção}$$

$$T_{int, clad}(z) = T_{out, clad}(z) + \frac{e}{k_c} q''_{max} [1 - b(z - z_{mid})^2]$$

$$T_{out, clad}(z) = T_{lead}(z) + \frac{q''(z)}{h}$$

$$T_{int, fuel}(r, z) = T_{out, fuel}(z) + \frac{q'''(z)}{4k_{ThO_2}} (r_1^2 - r^2) \quad r_2 \leq r \leq r_1$$

$$q'(z) = q'_{max} [1 - b(z - z_{mid})^2] \quad (q' \equiv W/m)$$



BENCHMARKING

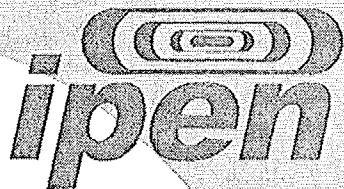
Grandeza medida	Resultado experimental	Resultado Calculado ^(a)
Fator de multiplicação	1,000 ± 0,001	0.9960 +/- 0.0030
$\sigma_{f(Th232)/\sigma_{f(U238)}$	0,26 ± 0,01	0.2500 +/- 0.0040
$\sigma_{n,\gamma(Th232)/\sigma_{n,\gamma(U238)}$	1,20 ± 0,06	1.2900 +/- 0.0004
$\sigma_{n,2n(Th232)/\sigma_{n,2n(U238)}$	1,04 ± 0,03	1.0900 +/- 0.0040

JEZEBEL consists of a mixture of
 Uranium (98,13% (U-235))
 enriched in uranium (5,33% (U-235))
 mixture of Uranium

Nuclear Data
 U-233; Th-232

Experimento	Resultado Experimental	Resultado Calculado ^(b)
JEZEBEL23	1.000 +/- 0.001	0.9945 +/- 0.00006
Caso 11	1,000 +/- 0,001	0.99326 +/- 0,0004
Caso 21	1,000 +/- 0,001	0.99536 +/- 0,0004
Caso 22	1,000 +/- 0,0011	0.99757 +/- 0,0004
Caso 31	1,000 +/- 0,001	0.99654 +/- 0,0004
Caso 32	1,000 +/- 0,001	0.99771 +/- 0,0004
Caso 61	1,000 +/- 0,0014	1.00134 +/- 0,0004

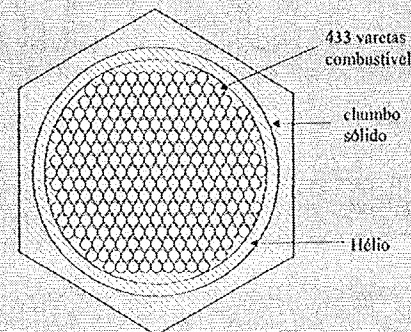
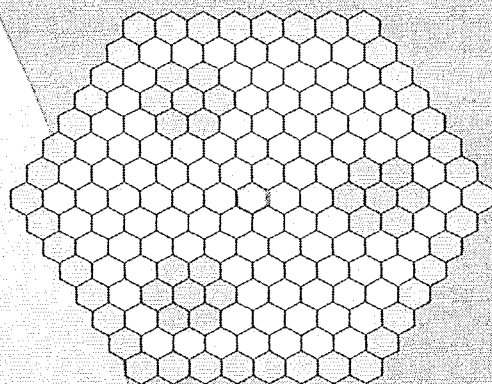
JEZEBEL-23 consists of a mixture of
 Uranium (98,13% (U-235))

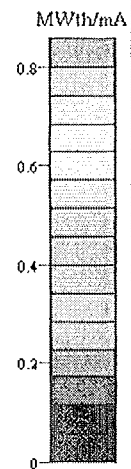
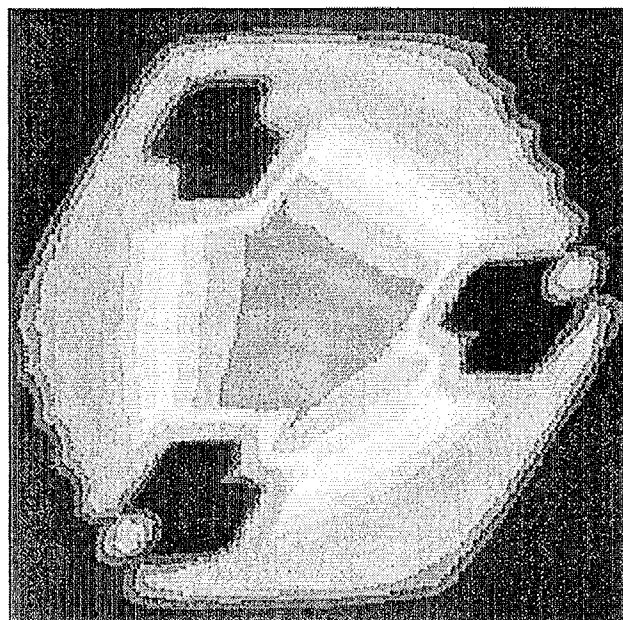


BOL Results

Curva 8

Nº médio de fissões/vareta	3,63
Nº médio de fissões/vareta/elemento	0,0340
Fator de pico	1,85
k_{eff}	0,965
Configuração	3 fontes pos. 3 5 anéis 106 elem. de diâmetro maior (433 varetas)





Núcleo do reator	
Potência térmica total (MWth)	105
Ganho	70
k_{eff}	0.965
Potência específica (W/g)	2.58
Densidade de potência (W/cm ³)	25.82
Fator de pico radial	1.854

Fig. 5(10) MW/V;

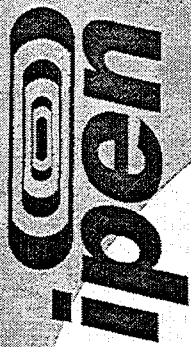
Fig. 4 MW/V



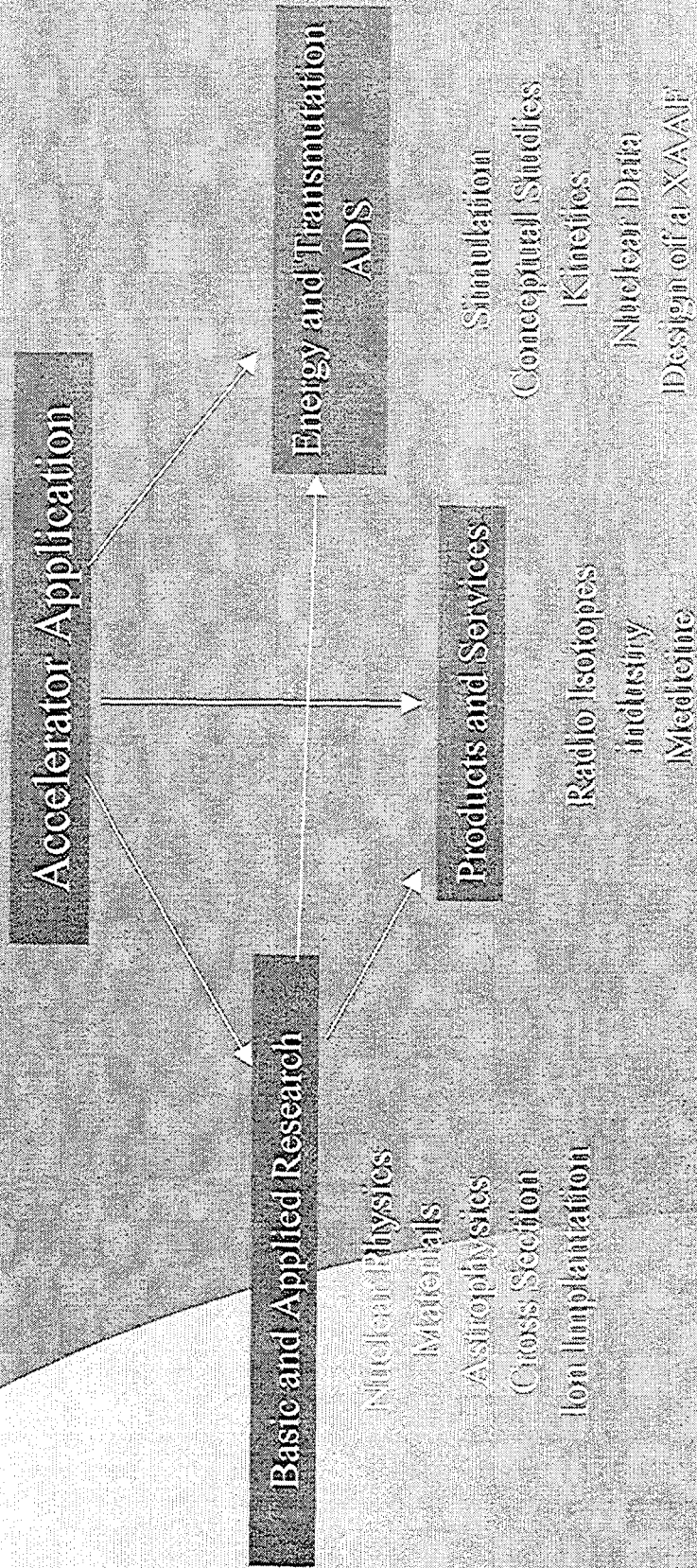
Recently(2002),
IPEN and the
Physics Institute
start negotiation
for a program
for accelerator
applications

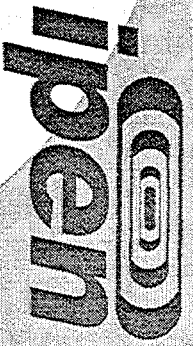
Accelerators Application- Proposal of a Program(Physics Institute-USP/IPEN)

- PELETRON(LAFN)-IFUSP
- LINAC-IFUSP
- MICROTRON-IFUSP
- CYCLOTRON- 28 MeV-IPEN
- Cyclotron 30MeV-IBA-IPEN
- ELECTRONS
ACCELERATORS(2)-IPEN
- Neutron Generator(14 MeV)-
Critical Facility(Water-Tank-100W)

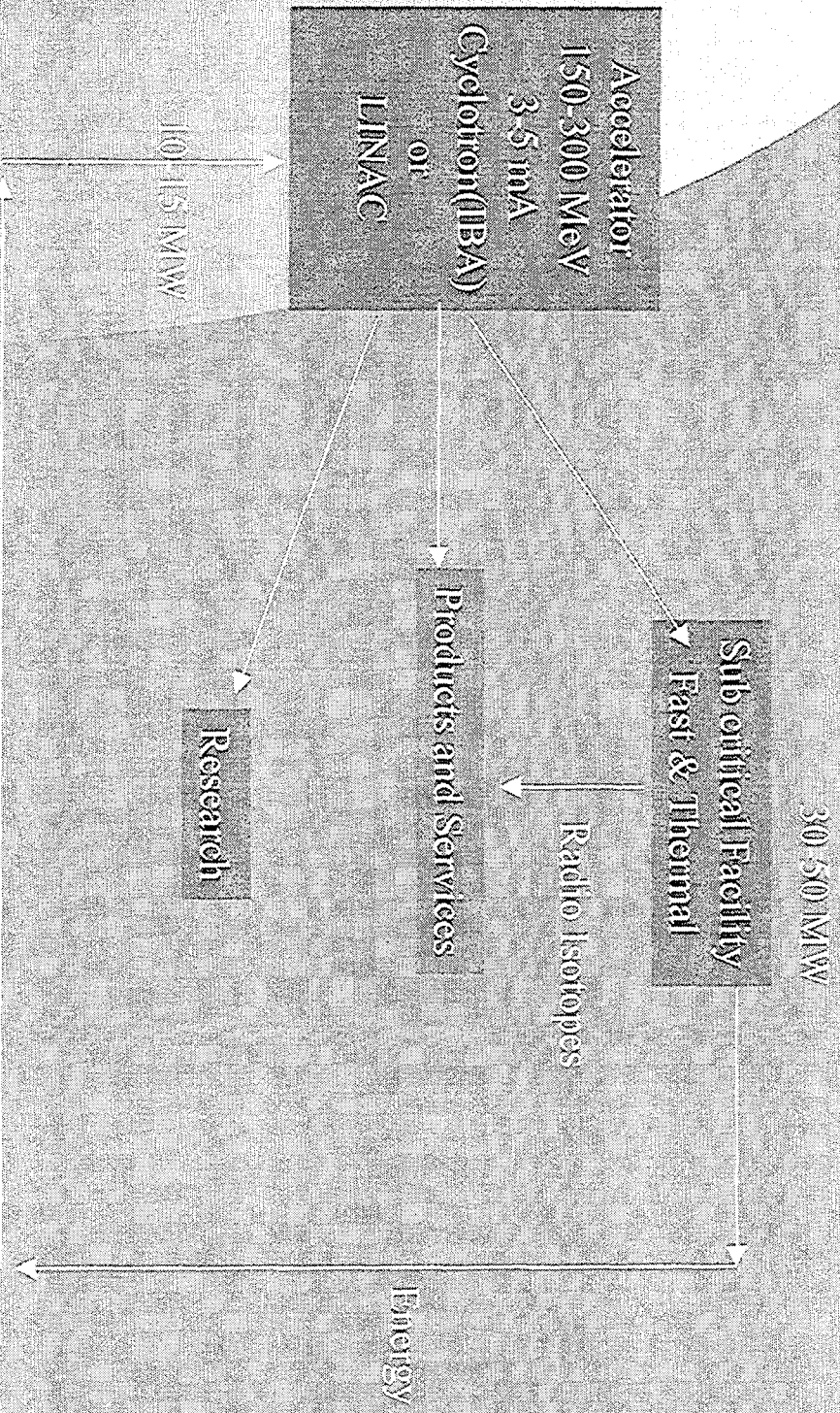


Accelerator Application-IPEN/FUSP

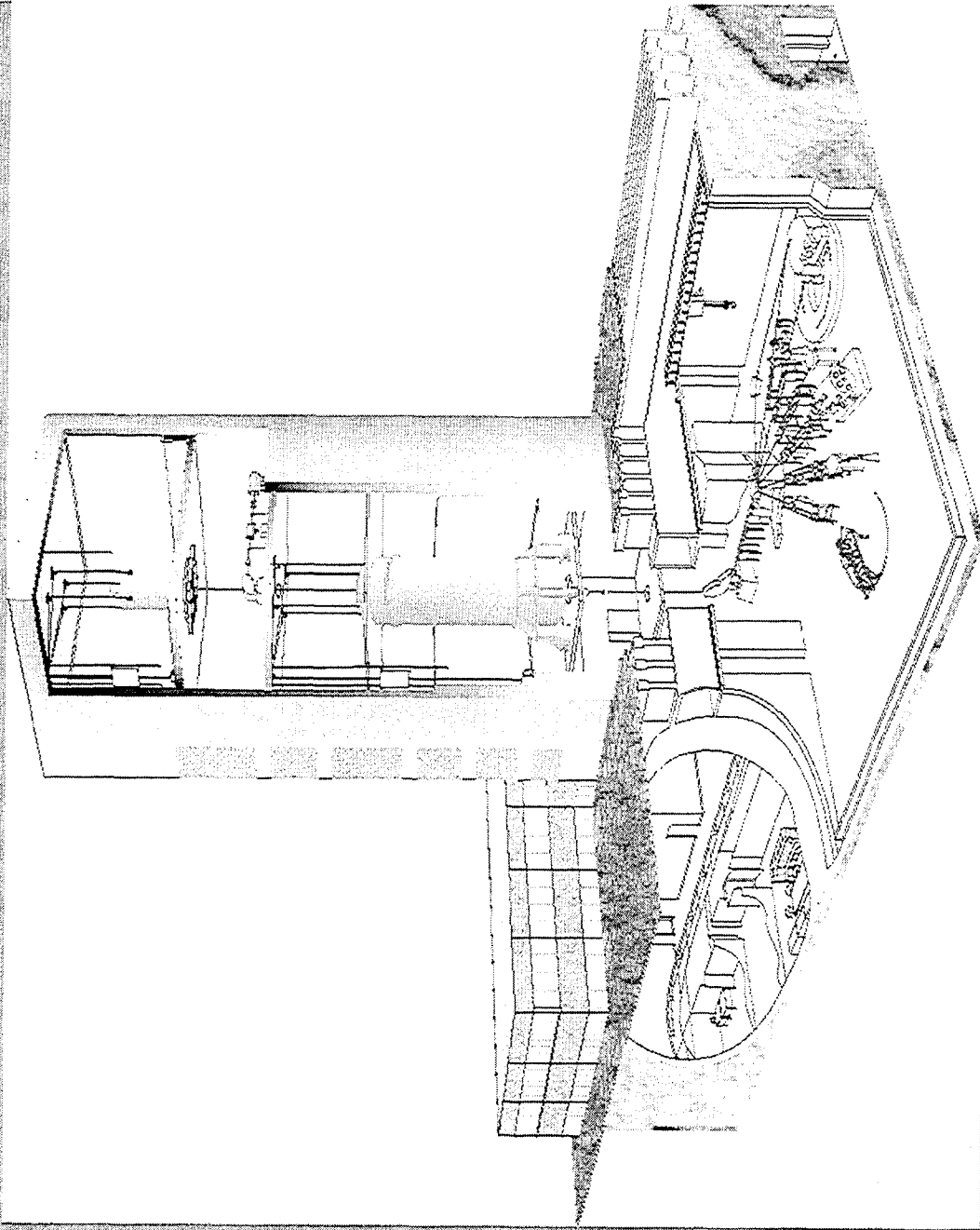
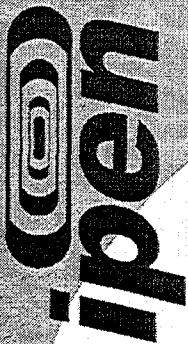


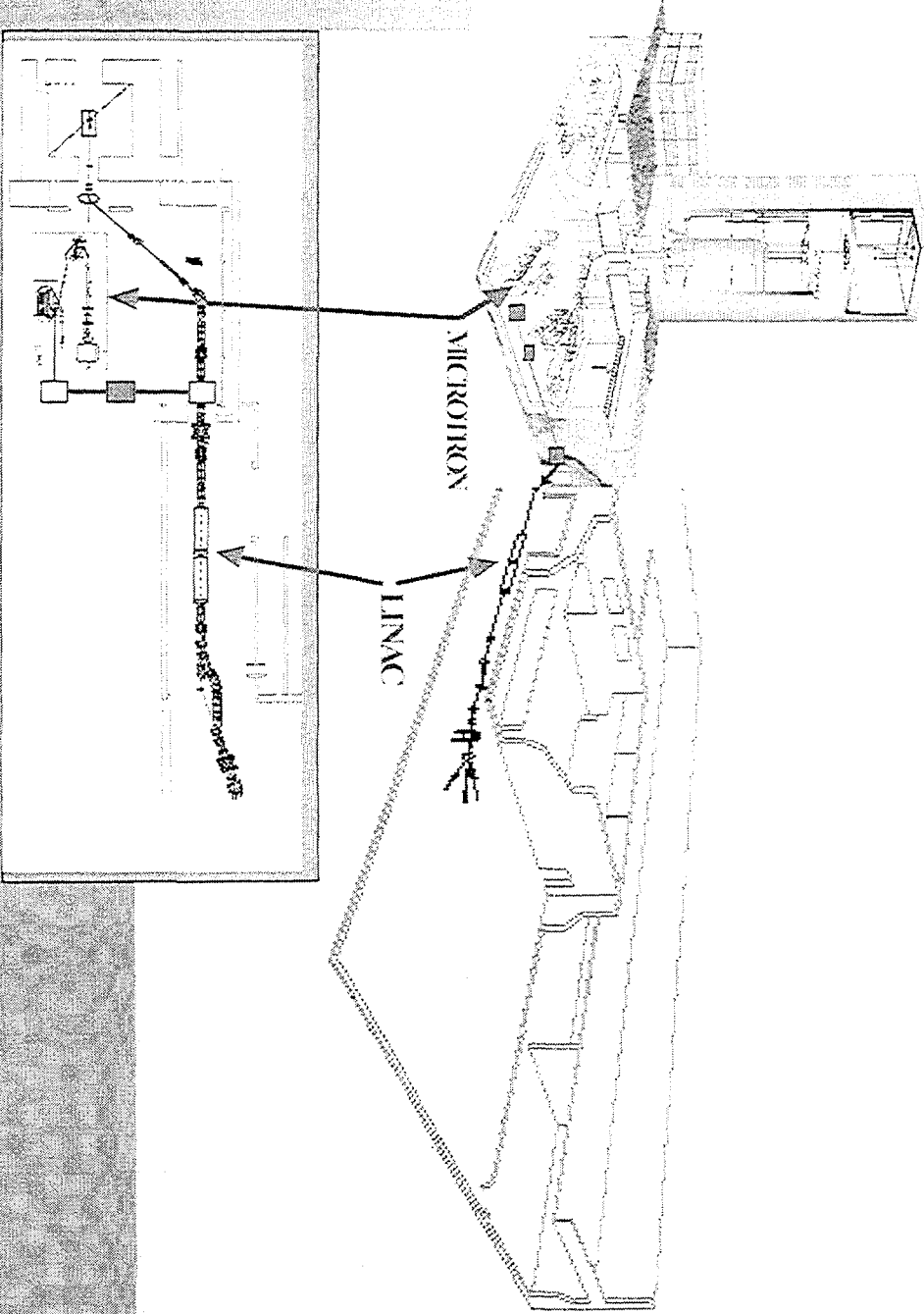
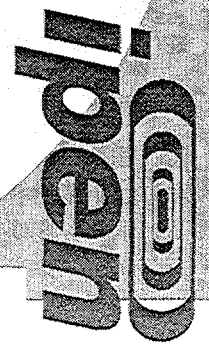


Road Map for Experimental Accelerator Application Facility (XAAF)



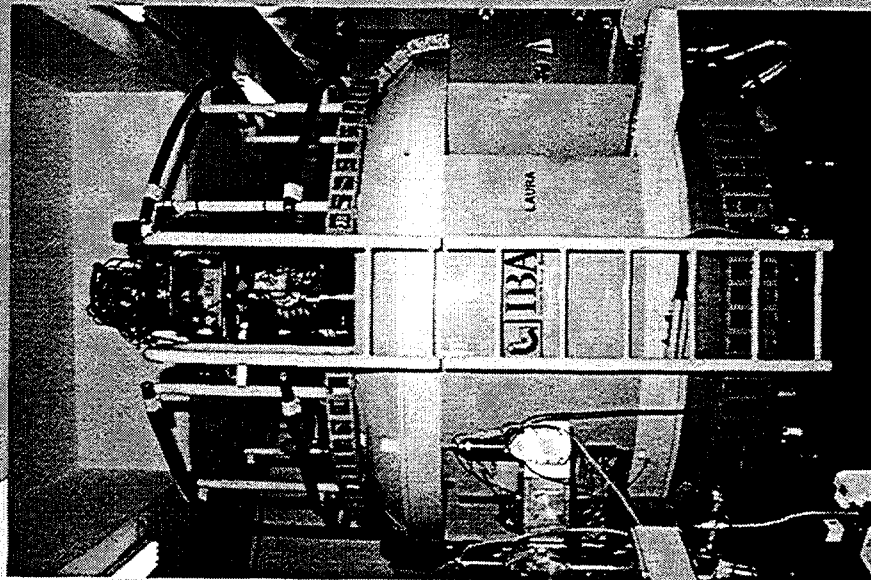
PELLETRON-IFUSP





Accelerator Lab JHFUSIP

CICLOTRONS DO IPEN



Ciclotrons do IPEN

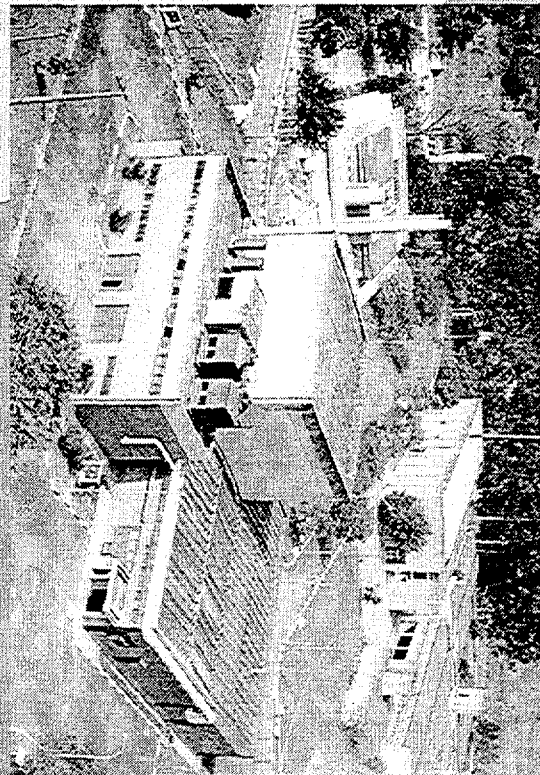
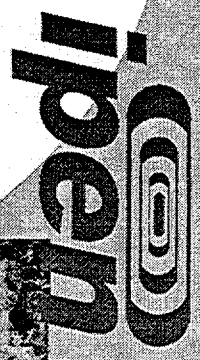
Ciclotron CV-28

fabricante: The Cyclotron Corporation (TCC) - USA;
tipo: isócrono, compacto e de energia variável;
prótons (24 MeV), deutérons (14 MeV),
 $^3\text{He}^{++}$ (36 MeV) e partículas alfa (28 MeV);
aplicação: pesquisa em geral.

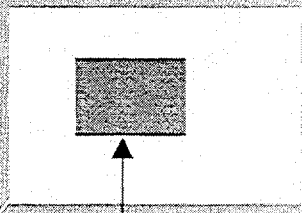
Ciclotron Cyclone 30

fabricante: Ion Beam Applications (IBA) - Bélgica;
tipo

isócrono, compacto e de energia variável; acelera
íons negativos e extrai prótons até 30 MeV;
corrente de feixe: até 350 μA
aplicação: produção de radioisótopos.



IPEN Criticality Facility



Neutron V/G
14 May

Coke Sub-critical

