THE IPR-R1 TRIGA MARK I REACTOR IN 39 YEARS: OPERATIONS AND GENERAL IMPROVEMENTS

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ABSTRACT

The nuclear IPR-R1 TRIGA Mark I Reactor operating in the Nuclear Technology Development Center, originally Institute for Radioactive Research in Minas Gerais, Brazil, was dedicated in November 11, 1960. Initially operating for the production of radioisotopes for different uses, it started later to be used in large scale for neutron activation analysis and training of operators for nuclear power plants. Many improvements have been made throughout these years to provide a better performance in its operation and safety conditions. A new cooling system to operate until 300 kW, a new control rod mechanism, an aluminum tank for the reactor pool, an optimization in the pneumatic system, a new reactor control console and a general remodeling of the reactor laboratory were some of the improvements added. To prevent and mitigate the ageing effects, the reactor operation personnel is starting a program to minimize future operation problems. This paper describes the improvements made, the results obtained during the past 39 years, and the precautions taken to ensure future safe operation of the reactor to give operators better conditions of safe work.

Key Words: research reactor, activation analyses, reactor improvements, reactor maintenance.

I. INTRODUCTION

The reactor of the Nuclear Technology Development Center (CDTN) is a compact and inherently safe reactor that now operates at a continuous power level of 100 kW. It utilizes a solid homogeneous fuel element, developed by General Atomic, in which the zirconium hydride moderator is homogeneously combined with 20% enriched uranium. That gives to the reactor the prompt negative temperature reactivity coefficient, limiting automatically the reactor power in the event of a power excursion [1].

The reactor core is located at the bottom of a tank under approximately 6.5 meters of shielding water, the open top of the reactor tank being at floor level. The irradiation facilities have physical and visual access to the core and large-volume assemblies can be irradiated through the water column as shown in Fig. 1

The reactor has three irradiation facilities. A rotary specimen rack with 40 positions, located in a well in the top of the graphite reflector, provides large scale isotope irradiation with neutron fluxes of same intensity.

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The central experimental tube (thimble) for conducting experiments for the irradiation of small samples is installed in the core region at the point of maximum flux. The pneumatic transfer tube makes possible the utilization of very short-lived radioisotopes.

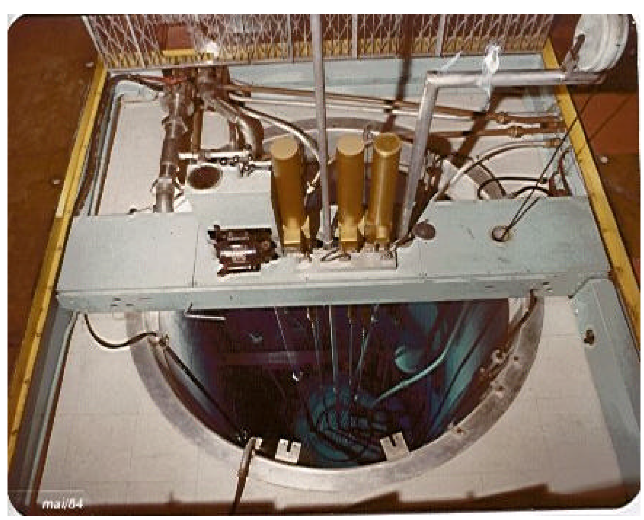

Figure 1. The IPR-R1 TRIGA Mark I Reactor

The reactor core consists of a lattice of 59 cylindrical fuel-moderator elements and 27 graphite elements, with the water of the tank occupying approximately 35% of the core volume. A radial graphite reflector surrounds the core that is water cooled by natural circulation.

II. HISTORICAL SYNOPSIS

Since its dedication on November 11, 1960, the IPR-R1 TRIGA Mark I Reactor has been successfully operated without any accidents.

In the beginning, it operated at a steady-state power of 30 kW which occasionally was leveled up to 100 kW. In 1972, modifications in the cooling system permitted upgrading the power to 100 kW permanently.

The reactor has been operated for the following purposes:

- Production of radioisotopes for the use in different educational and scientific institutions in the state and in the rest of the country;
- Scientific experiments;
- Training of nuclear engineers for research and power plant reactor operation;
- Experiments with materials and minerals;
- Neutron activation analysis. See Table I

TABLE I. Energy Released and Isotopes Produced

YEAR	ENERGY RELEASED (kW)	SAMPLES IRRADIATED AT IPR-R1	
		Neutron Activation Analysis	Experiments, Tests, Other Applications
1960	1,084	-	-
1961	47,151	08	476
1962	81,362	07	632
1963	15,232	06	742
1964	8,160	196	427
1965	9,725	476	525
1966	11,209	1,025	277
1967	12,973	5,908	369
1968	13,879	3,453	582
1969	37,8157	4,274	1,652
1970	30,659	23,453	558
1971	36,921	3,681	582
1972	60,266	6,044	936
1973	48,986	6,282	647
1974	70,648	10,566	839
1975	69,503	12,010	459
1976	95,160	19,424	444
1977	133,639	30,622	1,077
1978	136,499	49,422	379
1979	70,361	26,465	272
1980	89,906	31,235	197
1981	85,695	34,429	246
1982	101,897	57,061	194
1983	54,539	25,234	207
1984	51,999	19,518	180
1985	32,751	10,782	102
1986	31,615	10,835	179
1987	19,004	4,017	88
1988	24,492	7,408	56
1989	23,433	3,388	225
1990	13,827	2,149	112
1991	12,198	1,720	04
1992	20,298	2,898	25
1993	17,398	2,543	58
1994	5,945	1,089	15
1995	15,718	1,417	97
1996	29,769	1,820	142
1997	31,830	3,078	64
Totals	1,653,648	423,943	14,066

In the field of radioisotope production the material produced has been used like tracers (^{56}Mn, ^{59}Fe, ^{60}Co, ^{82}Br, ^{198}Au, ^{46}K) in oil pipeline flow studies, water flux in pumps and hydraulical turbines, mineral ducts erosion, control of high temperature furnace, and sedimentology and hydrology control.

Some isotopes were used in Medicine and Biological Studies to research endemies and tropical diseases. During its initial years of operation a large production of I-131 was used for thyroid diagnostics.

In reactor physics, experiments were developed in noise analysis techniques, cross section measurements, neutron spectrometry, reactivity measurements, neutron flux distribution in the reactor core, temperature effects on the fuel and other reactions.

The institute developed a special course in the operation of nuclear research reactors. This was in order to participate in the training program for operators of the brazilian nuclear power plants. To the present, there have been about 200 operators trained at the IPR-R1 Reactor.

Several samples of mineral ores were irradiated at IPR-R1 Reactor to determine Al, Cu, As, Au, Th, U, and others.

The largest amount of samples (about 400,000) were irradiated to dose uranium and thorium at the highpoint in the Brazil-Germany nuclear agreement [2].

In neutron activation analysis, a lot of samples were irradiated to analyze river and dam pollution, food contamination, contamination of paint used in nuclear installations, presence of heavy metal in the hair of individuals with leucopeny and in the blood of metallurgical employees.

The energy released and the total samples irradiated in 37 years are showed in Figures 2 and 3.

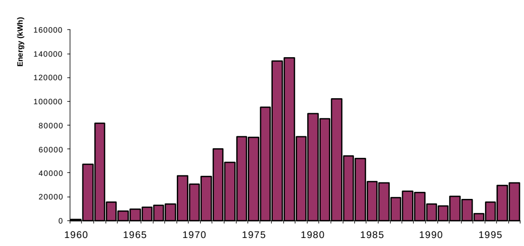

Figure 2. Energy Released in 37 Years

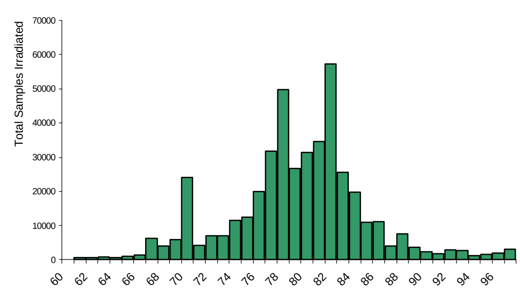

Figure 3. Total Samples Irradiated

III. IMPROVEMENTS AT IPR-R1 TRIGA Mark I REACTOR

Several changes were made in the original reactor design to ensure safer operation and better performance. These modifications improved the pneumatic transfer system, the cooling system, the reactor tank, the control rod mechanism, a neutrongraphy facility and the installation of a new reactor control console. In 1994, a general remodeling of the reactor building provided the Reactor Laboratory Room greater safety in the radiological and physical aspects.

IV. THE PNEUMATIC SYSTEM

The pneumatic transfer system provides fast insertion and removal of irradiated samples from the core. Through the years, uranium mineral ore analysis from different mines in the country increased greatly and a new transfer system was designed to provide for this increase. This system used mainly for uranium determination through delayed neutron technique, permitted an increase of 105 % in laboratory production results.

This increase made possible to control the results of three samples on the line and permitted an economy in reactor fuel burn-up. To enhance operator protection a system was designed with a special shielding surrounding the counter detectors [3].

V. THE WATER-WATER COOLING SYSTEM

The reactor core is cooled by natural convection of the pool water. To cool the water in the reactor tank, the contractor provided a system consisting of a Freon vapor-compression package chiller and associated plumbing. Several times, this system needed to be in operation during many days to provide the necessary cooling to the reactor tank for long time operation at 100 kW level. To fix this problem, the original system was changed by one water-to-water heat exchanger external to the reactor tank, followed by a heat-removal system on the secondary water loop which employs the evaporative-cooling principle. It should be noted that in using the water-to-water heat exchanger together with the evaporative cooling, the reactor water is in a closed-loop system [4].

The new system, that permits operating the reactor until 300 kW continuously, was incorporated to the reactor in 1972.

The water-treatment system, that keeps purity water consist of a mixed-bed mineralizer. To increase the system safety, a new separated bed mineralizer was installed on line with another distillation system.

Additional instruments were employed in the in/out primary circuit to detect and to warn the operators about any trouble in the cooling system such as a high level of conductivity, radiation and the current temperature and pressure levels of the pumps.

VI. THE REACTOR ALUMINUM TANK

After fourteen years of operation, the internal epoxy cover of the reactor tank began to separate from the steel tank. Pieces of the material and particles could be seen in the bottom of the reactor tank. After examination of the tank conditions, it was decided to remove the epoxy facing and substitute it by a new tank made of aluminum alloy AA-5052, recommended by the constructor of the reactor.

A complete operation plan was made to protect the reactor and the employees working in the dismantling of the reactor and its auxiliary systems. The water was put into a special aluminum tank made specially to keep it during the installation of a new tank and the fuel and graphite elements were removed for special places in the reactor room

After removing everything from the tank, the epoxy cover was sanded off from the concrete case in the steel tank wall and the new aluminum tank was placed with concrete between it and the old one. After six months of intensive work, the installation of all components permitted the regular reactor operation.

VII. THE REPLACEMENT OF THE CONTROL ROD DRIVE MECHANISMS

The control rod drive mechanisms, located on the bridge at the top of the reactor pool structure, consist of a motor and reduction gear that drives a rack and pinion, and a variable resistor for position indication. In the event of a power failure or a scram signal, all control rod assemblies are de-energized and the rods fall into the core.

Towards the end of the 70’s, it started to show problems in the switches and the magnets of these controls. To prevent an accident or a non-controlled operation, a new control rod assembly was acquired and the old one was replaced in 1979, after three months of studies to make sure that the new system could be adjusted to the reactor instrumentation [5].

VIII. THE NEUTRONGRAPHY FACILITY

Intent on improving the irradiation system, a neutrongraphy facility was installed in 1987 at IPR-R1 Reactor increasing the performance in the testing techniques. The facility is a mechanical dispositive that permits the conduction of the neutron flux from the core to the surface of the reactor tank at the level of reactor room floor. It is a vertical aluminum tube closed at the bottom end. This part is in contact with the core and through the upper side are placed the materials or samples to be analyzed and the shield to protect the person against neutron and gamma rays. The same alloy of other components inside the reactor tank were used with the intent to protect the reactor and prevent accidents as its dimension is limited, restricting the use of the system and the size of the samples [6].

IX. THE NEW REACTOR CONTROL CONSOLE.

The original control console was used until March 1997 having undergone some modifications made through these years to change old components or to substitute some obsolete equipment.

The equipment changed consisted of the strip charter recorders of the power channels and later the conductivity meter, the water and area radiation monitors, and the instruments to the new cooling system. Through the years, it various problems happened with replacement valves, circuits, transistors, and other components which caused frequent shutdowns in the reactor operation. Therefore the institute decided to project and to build a new control console [7].

During a two year period, groups of specialists from CDTN and the Nuclear Engineering Institute (IEN), researched and built a new control console , totally manufactured with solid state components wich is now in operation. The operation with the new console permited to operate the reactor with greater safety than the old one because improvements made the safety parameters [Figure 4].

Figure 4. The IPR-R1 Reactor New Control Console

X. THE REACTOR LABORATORY BUILDING REMODELED

The civil, electrical and hydraulical installations of the IPR-R1 Reactor building remained the same since its dedication in 1960. For various years the operation staff had requested a complete reform of the installations to increase safety during reactor operation [Figure 5].

During one year, several discussions between technicians and licencing personal of CDTN and the reactor operators team, a general project of remodeling of the Reactor Laboratory was concluded and submited to the personal of CNEN.

Figure 5. The Original Reactor Control Room

In June of 1994, after a meeting between technicians of CDTN and the Reactor Licensing Superintendence of CNEN, a general remodeling of several parts of the Reactor Laboratory began. The protection to the reactor installation was carefully studied and a casement of steel was built surrounding the reactor tank to protect it against any kind of damage and dust [Figure 6]

Figure 6. The New Reactor Room and the Reactor Pool Protector Casement

According to the Safety Analysis Report of the IPR-R1 Reactor, the modifications intended :

- to eliminate all problems of the 34 years old installation;
- to improve the physical safety of the building;
- to improve the safety during reactor operations;
- to adequate the installations to the new requirements of safety.

To better protect the operation team, the control console room was separated from the reactor room by constructing a new room for the operation control. The pneumatic system, installed inside of the reactor room, now have a separate room with complete facilities to process the samples.

The room where the operators temporally keep radioactive material was remodeled to better protect the material and the employees.

A new roof was installed on the reactor building to stop the rain water from falling directly on the concrete ceilings of the building to prevent flooding due to the deterioration of the old rain roof drains and infiltration through the roof [Figure 7].

To the cooling system room was given a new concrete roof without sky lights and with roof drainage system. A defense wall to protect the heat removal system was built around the room and access to the emergency exit of the cooling system room was facilitated.

The reactor room was completely modified to incorporate many improvements and provide greater safety during reactor operation. The false walls of amyanthus plates and its wood supports, that attract termites, were removed and a special vinyl plaster with a latex paint applied to make decontamination easier in case of accidents. The floor was repaved with concrete and an auto leveler covering was applied to provide more flexibility in accidents with contamination.

All doors were changed, the forced mechanical ventilation and the air conditioner overhauled, this with separated circuit for the reactor room and the control room.

The electrical and the hydraulical systems were modified and the operation panels were constructed with independent distribution for each different section.

Finally, the entire reactor building had its walls covered with a new facing and a special paint, allowing greater resistance to the problems of erosion and ageing.

XI. THE OPERATORS TRAINING PROGRAM

The Reactor operated until 1982 without an Emergency Plan, a Safety Analysis Report or an Operating Manual. In this year it was required that all nuclear research reactors to acquire a license from CNEN to operate [8].

The reactor staff and the licensing division provided the documents necessary to license the reactor and the operator team at it stipulated in the Operating Manual.

The first program was attended in 1982, with 240 hours of theoretical classes, reactor experiments, and radiological proceedings. The program is applied once every two years with about 180 training hours per program.

A complete health checkup is made each year to all operators and the program has a personal evaluation every 2 years. The final exams and the final license is given by CNEN through the Licensing and Control Coordination.

XII. INSPECTIONS AND CALIBRATIONS OF THE REACTOR SYSTEMS

The Reactor Operating Manual has the established parameters for inspections and calibrations, and its operational and auxiliary systems. Also the proceedings on preventive and corrective maintenance relative to all components that involve the safety operation of the reactor [9].

Following the Reactor Operating Manual's preventive maintenance check, it is necessary a daily verification of the functioning of the following systems:

- safety system of the reactor;
- radiation monitoring systems;
- reactor cooling system;
- air conditioner and forced ventilation;
- systems of the reactor room (The conditions and measurements obtained need to be registered in both the Reactor Operation Log Book and the Daily Verifications Schedule);
- monthly operation of the water purification system (In case of an eventual necessity the system can operated with more frequency);
- every six months inspect the electronic equipment of the Reactor Control Console;
- every six months inspect the components of the reactor control rod drives;
- annual control rod drop time and control rod calibration;
- verification of the operation characteristics of the neutron detector channels twice a year;
- annual visual inspection of the control rods and some fuel elements;
- calibration of the reactor power detectors twice a year;
- preventive maintenance of the reactor cooling components every three years; and
- periodical inspections of the air conditioners and forced ventilation system.

All problems, the corrective maintenance and/or repairs completed and the resulting system modifications need to be communicated to the Special Safety Commission and registered in the Reactor Operation Log Book.

XIII. CONCLUSIONS

During these thirty seven years the IPR-R1 TRIGA Mark I reactor has operated with a good performance record and its facilities have been increased through the years due to recommended modifications that were carried out and refurbishment projects.

The operation staff is planning to initiate a program to understand degradation mechanisms, assessment techniques and an appropriate mitigation process that can provide corrective responses to maintain safety in the operation and utilization of the reactor.

The adequate operation conditions and the preventive maintenance during these years has given to the reactor good perspectives relative to the aspects of ageing specially after all the modifications of the reactor systems and in the reactor building . The next step will be an upgrading of the reactor power level to 250 kW which will permit an increase in the number of irradiations and improve the perspective of nuclear experiments .

ACKNOWLEDGMENTS

This report cannot be complete without thanks to all operators and supervisors of the IPR-R1 TRIGA Mark I reactor, whom, during these thirty seven years have provided safe and optimum operation, avoiding any occurrence of accidents because of their great reactor operation skills.

REFERENCES

[1] GENERAL ATOMIC. **Triga Mark I Reactor mechanical maintenance and operating manual**. San Diego; Ca. 1960 . (GA-1544).

[2] TÓFANI, P.C., STASIULEVICIUS,R., SABINO, C.V.S., MARETTI JR, F. **The role of a research nuclear reactor within the framework of mineral prospection and processing programs.** Belo Horizonte: CDTN, 1982. (DEAT.PD-02)

[3] AMORIM, V.A.. **Segunda otimização da utilização do terminal pneumático TP-2 na dosagem de minério de urânio por nêutrons retardados.** Belo Horizonte: CDTN, 1980. (DEAT.PD/LABRE.PD-01/80)

[4] SILVA, V.M.. **Anteprojeto de ampliação da potência do Reator IPR-R1.** Belo Horizonte: IPR, 1976. Tese de Mestrado do Curso de Ciências e Técnicas Nucleares da Universidade Federal de Minas Gerais.

[5] MARETTI JR., F, AMORIM, V. A., COURA, J. G. **Resumo dos resultados obtidos nos testes de partida do reator TRIGA IPR-R1 após a troca do mecanismo de acionamento de barras.** Belo Horizonte: IPR, 1979. (LABRE.PD 05/79)

[6] AMORIM, V. A.. **Construção e instalação de um protótipo de extrator de nêutrons no reator IPR-R1.** Belo Horizonte: CDTN, 1987. (AT-002/87).

[7] FERNANDES, M. P.. **Comparação entre a nova instrumentação proposta para o Reator IPR-R1 e a original.** Belo Horizonte: CDTN 1992. (AT-NT-003/92)

[8] NUCLEBRÁS S/A. **Relatório de análise de segurança do Reator TRIGA IPR-R1.** Belo Horizonte, CDTN, 1982.

[9] NUCLEBRÁS S/A. **Manual de operação do Reator TRIGA IPR-R1.** Belo Horizonte: CDTN, 1982.

Figure 7. The New Roof of the Reactor Building