THIRTY FOUR YEARS OF THE IPR-R1 TRIGA MARK I REACTOR: PERFORMANCE, IMPROVEMENTS AND FUTURE INITIATIVES.

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Abstract

The nuclear TRIGA Mark I Reactor manufactured by General Atomic, a Division of General Dynamics Company for the Nuclear Technology Development Center, originally Institute for Radioactive Research, in Minas Gerais, Brazil, was dedicated on November 11, 1960. Initially operating for production of radioisotopes for different uses and neutron activation analysis, later the reactor started to be used on training and materials research. Throughout the years many improvements have been made to provide for a better performance in its operation and safety conditions. Among the changes made of greater interest were, a new cooling system, a new control rod mechanism, an aluminum tank to the reactor pool, an extra pneumatic system and a new reactor control console. The reactor does not have any program of prevention and mitigation of ageing effects, but is intent on starting one to prevent future problems in the operation. This paper describes the improvements and the results obtained during these 34 years of the operation and the initiatives for the future of this TRIGA MARK I Reactor.

1. INTRODUCTION

The reactor of the Nuclear Technology Development Center (CDTN) is a compact and inherently safe reactor that operates right now at 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 coefficient of reactivity, 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.[Figure 1]

The reactor has three irradiation facilities. A rotary specimen rack with 40 positions, located in a well in the top of graphite reflector provides large scale isotopes irradiation with neutron fluxes of comparable intensity. The central experimental tube (thimble) for conducting experiments of irradiating 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.

The reactor core consists of a lattice of 58 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 cooled by natural circulation of water.

A cooling system is provide to remove the heat from the reactor tank. The heat removal system of the IPR-R1 reactor is a water-to-water heat exchanger.

2. HISTORICAL SYNOPSIS

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

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

The reactor has been operated for the following purposes:

1) Production of radioisotopes for use by different educational and scientific institutions in the state and the rest of the country;
2) Scientific experiments;
3) Training of nuclear engineers for research and power plant reactor operation;
4) Experiments with materials and minerals;
5) Neutron activation analysis. (Table 1)

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 oildutes flow studies, water flux in pumps and hydraulical turbines, mineral dutes erosion, control of high furnace, and sedimentology and hydrology control.

Some isotopes were used in Medicine and Biological Studies to research endemies and tropical diseases. During its first 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 Brazilian Nuclear Power Plants. To the present, there have been about 140 operators trained at the IPR-R1 Reactor. [2]

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.[3]

In the neutron activation analysis, a lot of samples were irradiated to analyze river and dam pollution, food contamination, the contamination of paint used in nuclear installations, the presence of heavy metal in the hair of individuals with leucopeny and in the blood of metallurgical employees. [4]

3. IMPROVEMENTS AT IPR-R1 TRIGA MARK I REACTOR

Several changes were made in the original reactor design to insure 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.

3.1. The pneumatic system

The pneumatic transfer system provides fast insertion and removal of irradiated samples from the core. This system has a blower, a filter, solenoid valves, a control box, and associated plumbing . The piping from the blower extends to both terminal points of the pneumatic transfer system to supply a pressure differential for the injection or ejection of the samples. The original transfer tube can be located in any position at the core. Since the beginning it has been located at the position F12 permitting many types of analysis.

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. In order to provide better performance in analysis a system was developed to optimize the time control of the irradiation and was located outside the cylindrical graphite reflector.This system used mainly for uranium determination through delayed neutron technique, permitted an increase of 105 % in laboratory production results.

This increase made it possible to control the results of three samples on the line and permitted an economy in the reactor fuel burn-up. Intent on the protection of the operator, a system was designed with a special shielding surrounding the counter detectors.[5]

3.2 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 to provide cooling to the reactor tank in long operations at 100 kW level, this system needed to be in operation during many days. Through the years, problems resulted with the demand of analysis and production of isotopes increasing and the institute decided to change the system to a 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. [6]

The new system, that permits operating the reactor at 250 kW continuously, was incorporated to the reactor in 1972, and the operation staff decide to leave both systems in operation : the Freon vapor-compression and the water-to-water heat exchanger external. Eight years later, the Freon system started to deteriorate due low use and it was removed from the operation.

The water-treatment system that keeps the purity of the water is maintained by a water-treatment system consisting of a mixed-bed mineralizer, pump, filter, flowmeter and associated plumbing. Intent on increasing the 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 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.

3.3. The Reactor Aluminum Tank

After 14 years of operation, the internal epoxy cover of the reactor tank began to separate from the steel tank. Pieces of the material loosened itself in the water of the reactor tank and the particles could be seen in the bottom of the reactor tank. After close examination of the tank conditions, the reactor head decided to remove the epoxy facing and order the construction of a new tank in the aluminum alloy AA-5052, this recommended by the constructor of the reactor.[7]

A complete operation plan was realized to protect the reactor and the employees working in the dismounting of the reactor and its auxiliary systems. After some months of preparation, the technicians got ready to start the operational program. The fuel elements and graphite elements, all equipment and plumbing, the rotatory specimen rack, the reflector, and the detectors were removed from the reactor tank. The water was put into a special aluminum tank made specially to keep it during the installation of a new tank

After everything was removed 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. The supervisor of the reactor provided a complete non-destructive testing for the tank and a complete chemical analysis was realized. After six months of intensive work, the installation of all components permitted the regular reactor operation. [8]

3.4. 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. Each rod has an extension tube which extends to a dashpot below the surface of the water. The dashpot and control-rod assembly are connected to the rack through an electromagnet armature. 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 have some troubles in the switches and the magnets of these controls. Sometimes the switches mounted in the drive assembly did not function well and many times during the manual operation, the rods themselves started to move without operator manipulation. 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.

3.5. 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 of the reactor to the surface of the reactor tank at the level of reactor room floor. It is a vertical tube of aluminum 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.[10]

Before the neutrongraphy system began to be used, many tests were realized and a rigorous control of doses and planning uses was established.

3.6. The New Reactor Control Console.

The original control console is still in use although having under gone some modifications made through the years to change old components or to substitute some obsolete equipment.

The first equipment changed was the strip charter recorders of the power channels with modifications in the log N and linear circuits. Later the conductivity meter and the water and area radiation monitors are substituted and the instruments to the new cooling system were added to the console.

Through the years, various problems with replacement of valves, circuits, transistors and other components which caused frequent shutdowns in the reactor operation. The institute tried to buy a new console, but to due the high cost a special commission decided to project and build the console in another institute of the Nuclear Energy National Commission (CNEN). [11]

During two years groups of specialists from CDTN and the Nuclear Engineering Institute (IEN), researched and built a new control console , totally manufactured with solid state components and now it is ready to substitute the old one. The operation staff are just waiting for the licensing from CNEN to begin the change that will permit it to operate the reactor with greater safety than the old one because the original operational principles were honored using only solid state components and some of them were duplicated. [Figure 2]

4. THE REACTOR LABORATORY BUILDING REMODELED

The civil, electrical and hydraulical installations of the IPR-R1 Reactor building continued 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 the reactor operation.

In June of 1994, after a meeting between technicians of CDTN and the Reactor Licensing Superintendency of CNEN, a general remodeling of several parts of the Reactor Laboratory began. The protection to the reactor installation was carefully studied and a casemente of steel was built surrounding the reactor tank to protect the reactor against any kind of damage and dust. [Figure 3]

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

a) to eliminate all problems of 30 years installation;
b) to improve the physical safety of the building
c) to improve the safety during operations of the reactor;
d) to adequate the installations to the new requirements of safeness.

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 mechanical office, a compartment in the reactor room, was separated and now has conditions to attend the small repairs of the reactor and auxiliary systems.

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 onto the concrete ceilings of the building to prevent flooding due to the deterioration of the old rain roof drains and infiltration through the roof.

The cooling system room was given a new concrete roof with sky lights and 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 modifications 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.

The old windows and sky-lights, installed in the original construction, were removed and fixed windows were placed close to the roof to provide natural illumination to the reactor room. 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, permitting new illumination to the reactor and a new network of plumbing, pneumatics, detectors and instrumentation cables.

Finally the entire reactor building had its walls covered with a new facing and a special paint, permitting greater resistance to the problems of erosion and ageing. [Figures 4 and 5]

5. THE OPERATORS TRAINING PROGRAM

The Reactor had been in operation until 1982 without an Emergency Plan, a Safety Analysis Report or an Operation Manual, because just in this year the CNEN required all nuclear research reactors to aquire a license from the CNEN to operate. [12]

The reactor staff and the licensing division of that year provided the documents necessary to license the reactor and the operator team. It was stipulated in the Operation Manual that a complete training program was to be initiated for the operators and supervisors of the IPR-R1.

The first program was attended in 1982, with 240 hours of theoretical classes, reactor experiments, radiological proceedings and a complete program to review the documentation of the reactor operation. The program continued once every two years with about 180 training hours per program.

At the time present, this program continues to be offered. Also in an effort to increase its effectiveness, specialists in the area have been invited to provide new information and discuss the problems concerning reactor operation.

An complete health checkup is made each year of all operators and the program has an personal evaluation every 2 years. At the end of each evaluation the coordinator of the program is changed. The final exams and the final license is given by CNEN through the Licensing and Control Coordination.

6. INSPECTIONS AND CALIBRATIONS OF THE REACTOR SYSTEMS

The Reactor Operation Manual has the established parameters for inspections and calibrations of the reactor and its operational and auxiliary systems. Also the proceedings on preventive and corrective maintenance relative to all components that involve the safety operations of the reactor. [13]

Follow the Reactor Operation Manual's preventive maintenance check:

A. Daily verification 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 be registered in both the Reactor Operation Log Book and the Daily Verifications Schedule.

B. Monthly operation of the water purification system. In case case of an eventual necessity the system can operated with more frequency.

C. Every six months inspect the electronic equipment of the Reactor Control Console.

D. Every six months inspect the components of the reactor control rod drives.

E. Annual control rod drop time and control rod calibration.

F. Verification of the operation characteristics of the neutron detector channels twice a year.

G. Annual visual inspection of the control rods and some fuel elements.

H. Calibration of the reactor power detectors twice a year.

I. Preventive maintenance of the reactor cooling components every three years.

J. Periodical inspections of the Air Conditioners and forced Ventilation System.

In case of problems with the equipment or components of the reactor, the corrective maintenance determines that:

A. That reactor operations need to be suspended to repair the equipment.

B. If the maintenance service request requires a longer period to be completed, all the reactor operators need to be advised as to the scheduled return of reactor operation.

C. The planning of the maintenance must resolve the problem definitely.

D. The new system or component needs to be exhaustively tested to guarantee perfect functioning conditions.

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

7. CONCLUSIONS

During these thirty four 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 an utilization of the reactor.

The adequate operation conditions and the preventive maintenance during these years has given to IPR-R1 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 .

A program of studies has been started to examine fuel ageing through corrosion as a result of a visit by a IAEA expert to the reactor in 1994.

CDTN is interested in cooperating in a program of management and mitigation of ageing effects with other organizations and reactor operators to provide for future safe operation and utilization of the IPR-R1 TRIGA MARK-1 reactor.

8. ACKNOWLEDGMENTS

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TABLE I . OPERATIONAL DATA OF THE IPR-R1 TRIGA MARK I REACTOR

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	37,815	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	70,630	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	32,756	10,782	102
1986	31,615	10,835	179
1987	18,999	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	19,893	2,898	25
1993	17,398	2,543	58
1994	5,945	1,089	15
Total	1,575,806	397,628	13,763