MEXICAN TRIGA MARK-III REACTOR

F. AGUILAR-HERNÁNDEZ

Instituto Nacional de Investigaciones Nucleares
La Marquesa, Estado de México
México
E-mail: fortunato.aguilar@inin.gob.mx

Abstract.

The Mexican TRIGA Mark-III reactor started operations in November 1968, the main objectives for the reactor were: to make research for the peaceful uses of the nuclear energy and to prepare personnel to support the Mexican Nuclear Program. The reactor core was loaded with low enrichment fuel for 20 years, in November 1988 high enrichment fuel was loaded to the C and D ring, since then until November 2011 the reactor had a mixed core. The reactor conversion from high to low enrichment started in November 2011 and was finished in March 2012.

1. INTRODUCTION

1.1. The reactor site

The TRIGA Mark III reactor is located in the Centro Nuclear "Dr. Nabor Carrillo Flores". It is the main installation of the Instituto Nacional de Investigaciones Nucleares (ININ), which is located near the highway that joins Mexico City and Toluca City and is surrounded by forest. The nuclear center has, besides the reactor, other installations such as linear accelerator, gamma ray irradiation plant, radiopharmaceuticals production plant, and some other facilities (Fig. 1).

FIG. 1. The Centro Nuclear "Dr. Nabor Carrillo Flores".

1.2. The reactor building and the reactor hall

In the area of reactor building are located the radiopharmaceuticals production plant, the hot cells facilities, chemical and radiochemical labs, researchers and administrative offices (Fig. 2).

The reactor hall is spacious; it has enough space to accommodate the reactor concrete structure, the neutron activation labs, the control room and the offices for the reactor operating personnel (Fig. 3).

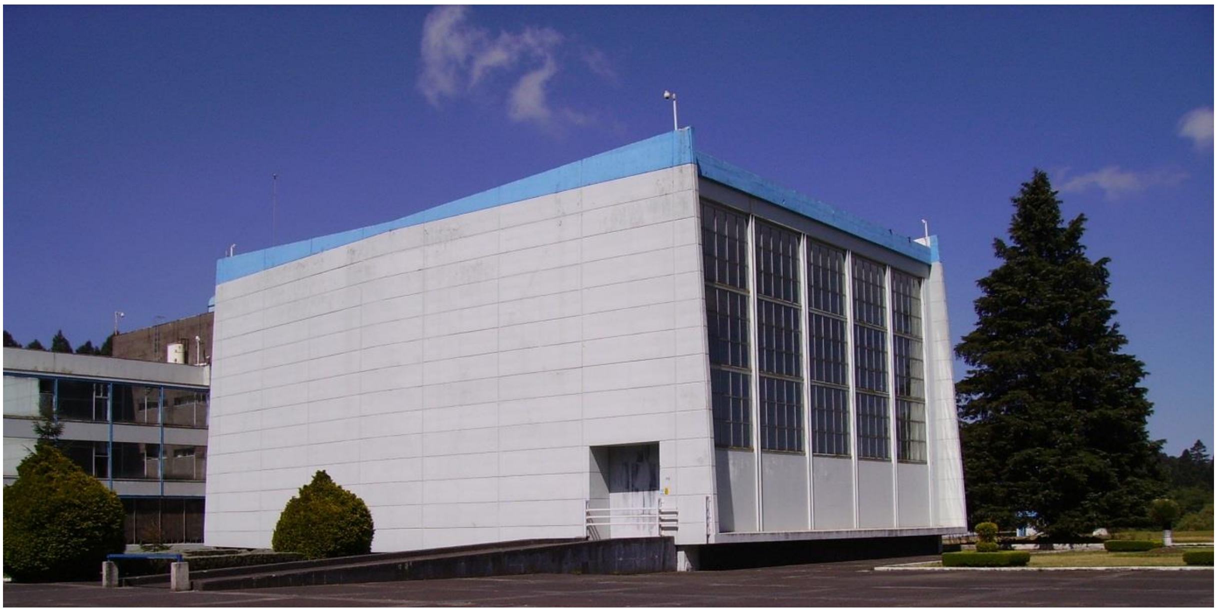


FIG. 2. The reactor building.

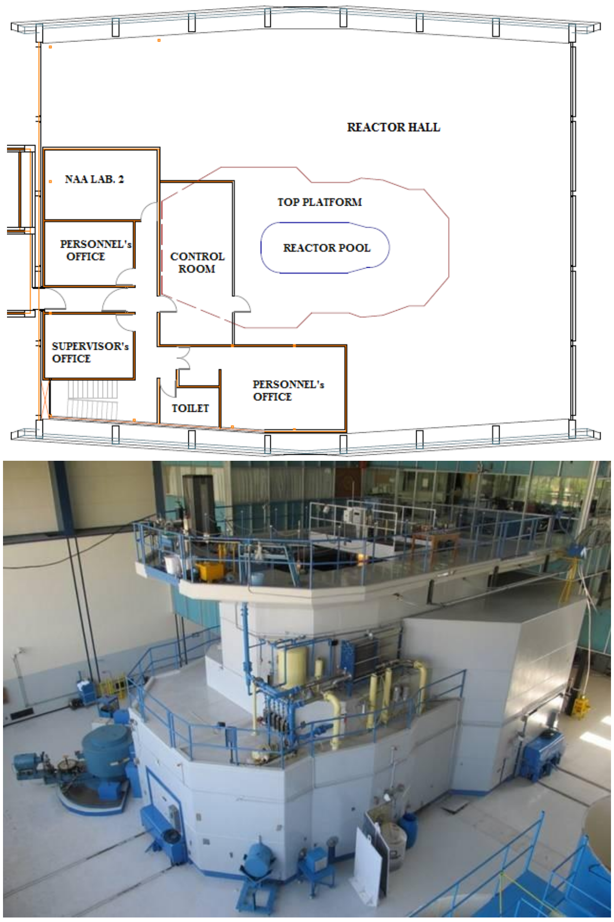


FIG. 3. Reactor hall schematic view and general reactor view.

2. TRIGA MARK-III REACTOR

2.1. Brief reactor description [1]

The TRIGA Mark-III reactor was designed, constructed and installed by General Atomics (G.A.) in the years 1964 through 1968, and first went critical on November 8, 1968. The TRIGA Mark-III reactor operates routinely at steady-state thermal power levels up to 1000 kW. It is a research reactor with a large and deep water-filled open pool; its walls and floor consist of a completely welded aluminum tank embedded in the shielding concrete structure.

The reactor core (active zone) is located near the bottom of the pool, and is suspended from a movable bridge that can be moved along the pool. The pool is approximately 7.62 m long, 3.048 m wide and 7.62 m deep. The cooling of the reactor is by natural convection of the pool water, the reactor can be operated at full steady-state power at any position in the pool.

The experimental facilities for neutron and gamma radiation studies can be classified as in-core facilities and out-core facilities. The in-core facilities are the central thimble, the terminus for the pneumatic transfer system, and at least three empty fuel positions are going to be used as in-core irradiation facilities; meanwhile the out-core facilities are: a rotating facility which is surrounding the core (lazy Susan), high-radiation-level dry exposure room (3.68 m long 3.05 wide and 2.74 high), radial and tangential beam ports, horizontal and vertical thermal columns. The access to the in-core facilities and the lazy Susan is done from the reactor bridge, whilst the access to the thermal column and the exposure room is by opening the high density concrete doors and for the radial and tangential beam ports is after removing partially or totally its shielding. To use the exposure room, the thermal column or the beam ports, it is necessary to raise the Lazy Susan and move the bridge to the desired facility (Figs. 4 - 6).

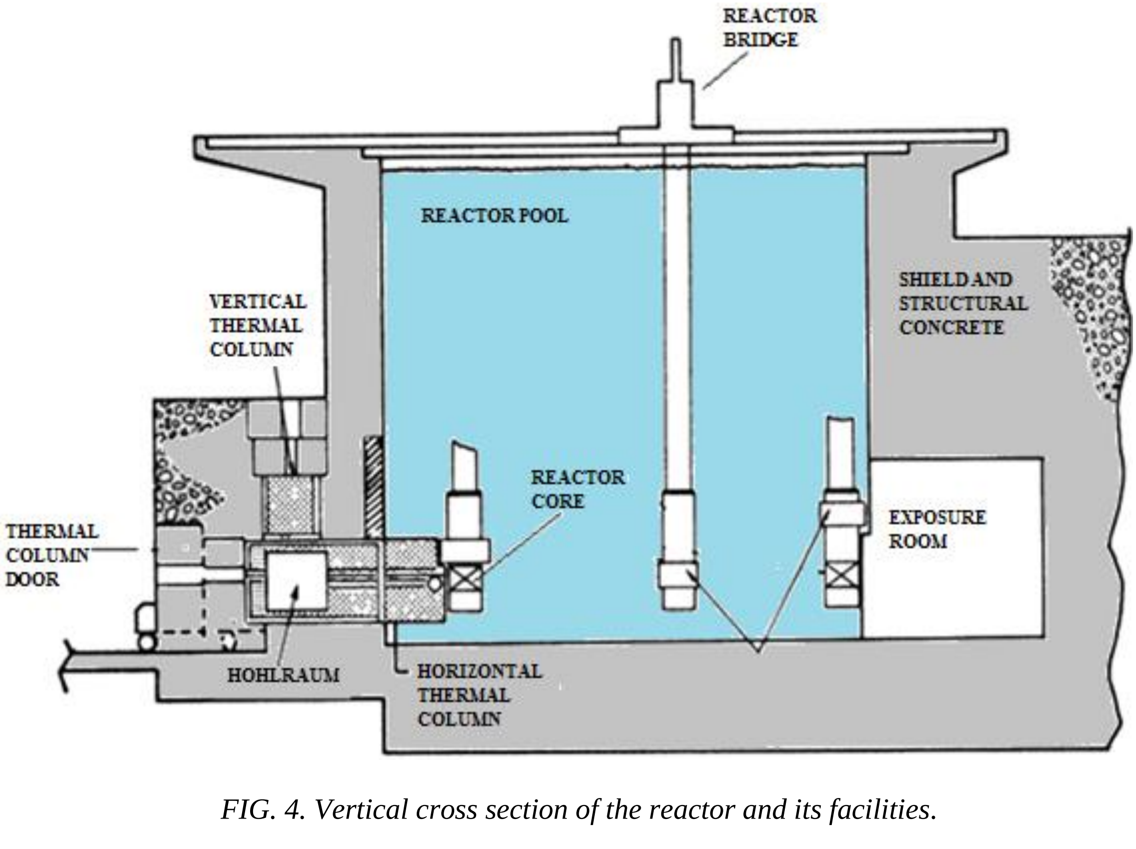


FIG. 4. Vertical cross section of the reactor and its facilities.

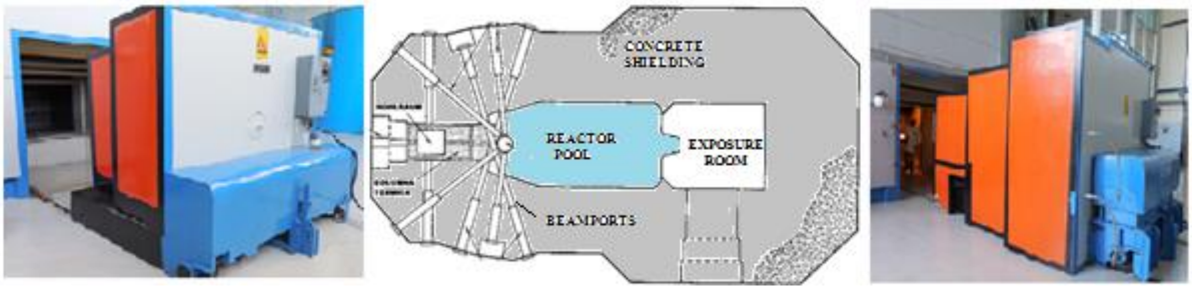
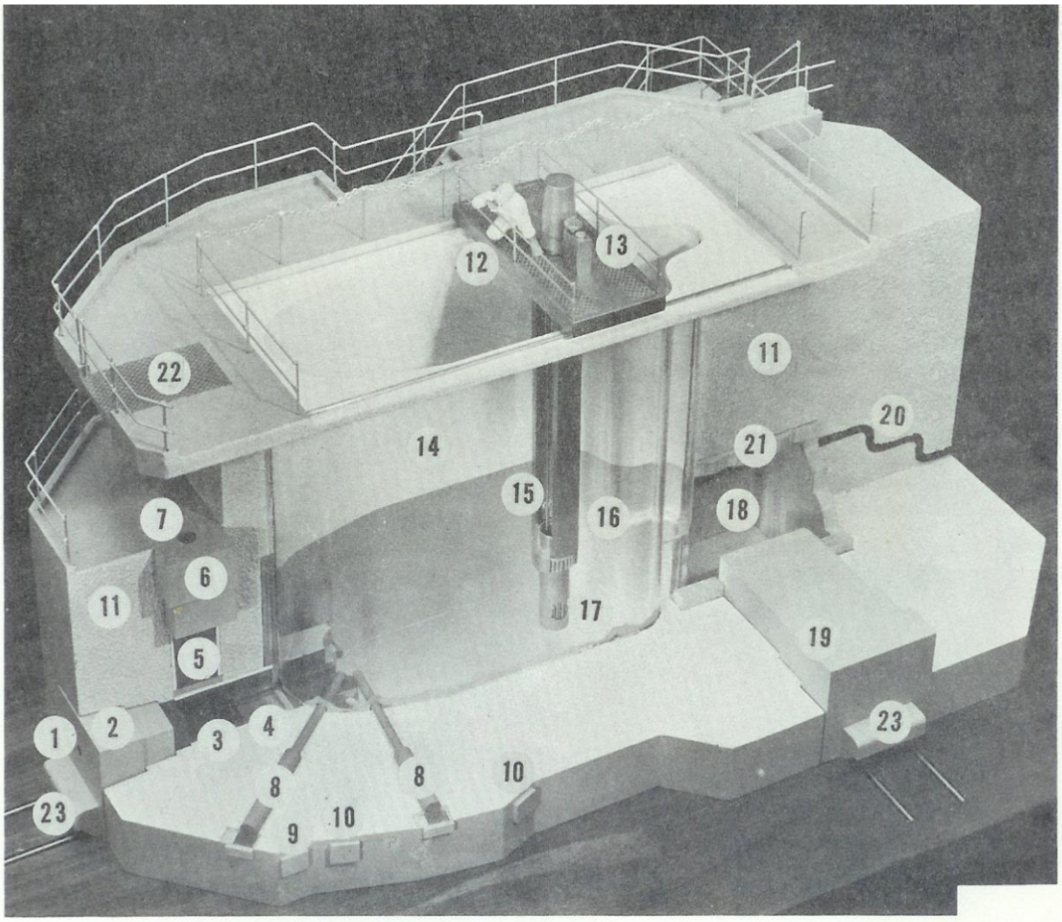


FIG. 5. Horizontal cross section of the reactor and its facilities: The thermal column and the exposure room access are shown in separate photos.



1. Stringer Access Port
2. Thermal Column Shield Door
3. Hohlraum
4. Horizontal Thermal Column
5. Vertical Thermal Column
6. Vertical Thermal Column Shield Door
7. Vertical Access Port
8. Radial Beam Ports
9. Thermal Column Access Port
10. Intersecting Through Ports
11. Concrete Shielding
12. Movable Bridge
13. Control Rod Drives
14. Full Height Aluminum Reactor Tank
15. Pneumatic Transfer System (Rabbit)
16. Isotope-Production Facility (Lazy Susan)
17. Reactor Core
18. Exposure Room
19. Exposure Room Shield Door
20. Experimental Access Conduits
21. Borated Concrete Exposure Room
22. Removable Plate for Access to Vertical Thermal Column
23. Enclosed Door Drive

FIG. 6. Model of TRIGA Mark III reactor.

2.2. The reactor core and its history [1, 2]

The reactor core has 126 positions in 6 concentric rings surrounding the central thimble, each ring is identified with a letter from B to G. The B ring is the inner one with 6 positions; the next is the C with 12 positions, D with 18, E with 24, F with 30 and G with 36. Each position in the rings is numbered in the clockwise direction, starting on the right side of one horizontal line that cut the core by the centre. The structural components are the top and bottom grid support plates; these are fastened to the cylindrical core shroud. The shroud is fixed to the bridge by two 38.1 aluminum channels approximately 5.5 m long (Fig. 7).

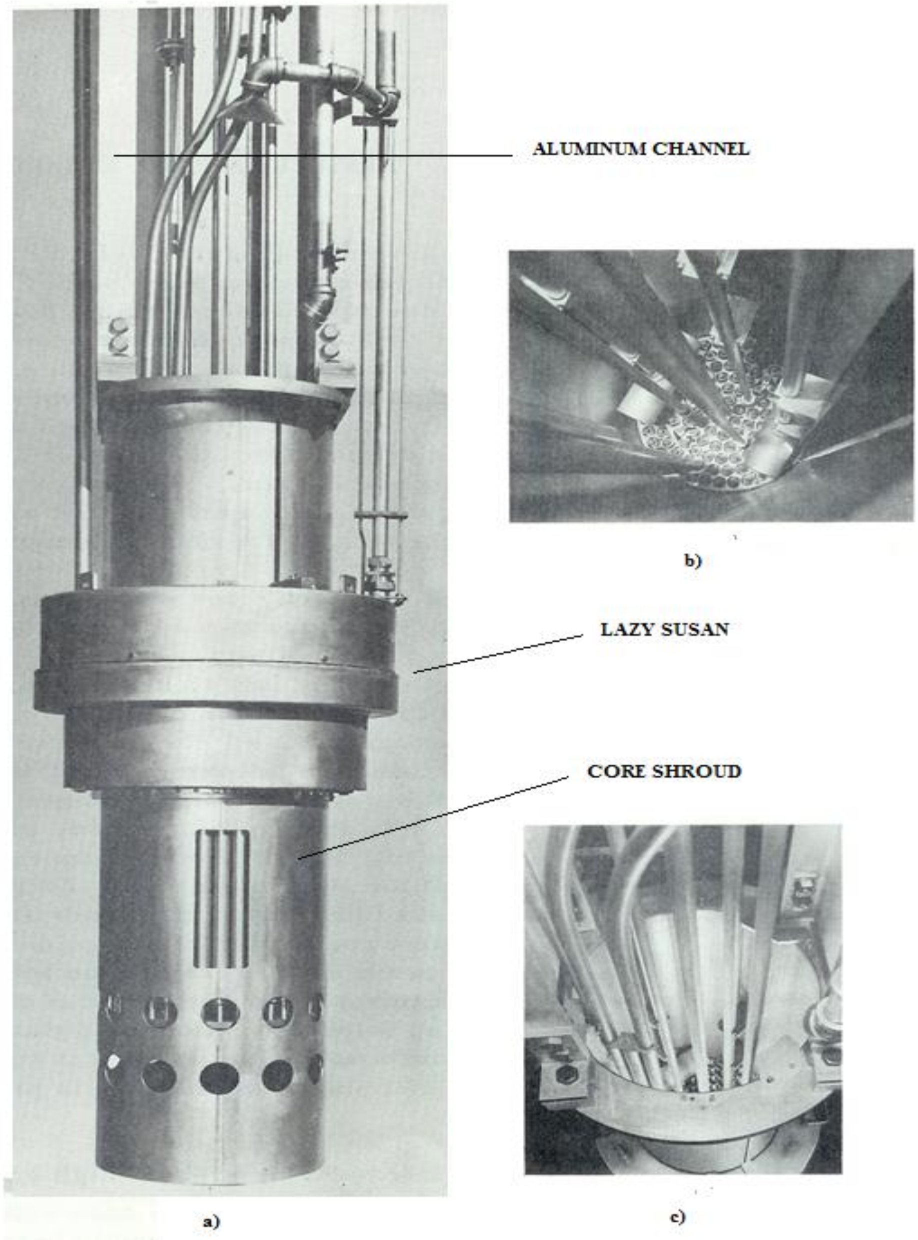


FIG. 7. Structural components for the reactor core; a) core shroud and lazy Susan, b) view of the top support plate and c) upper end of the core shroud.

The first reactor criticality was in November 8, 1968. The reactor core had 79 low enriched (20% of ^{235}U) fuel elements, four control rods three with fuel follower (FFCR) and the transient rod, additionally there were 41 graphite dummy elements, 6 in F ring and 35 in

G ring. In August 4, 1975 the 6 graphite dummy elements in F ring were replaced by fuel elements, since then until November 1988 the reactor used only low enriched fuel elements, from 1988 until November 2011 the reactor core had low and high enriched (70% of ^{235}U) fuel elements, 59 low in B, E and F rings and 26 high and 3 FFCR high in C and D rings and the transient rod in C-4 position. The low and high enriched fuel elements had the following composition: 8.5% U, 89.9% Zr and 1.6% H, the ^{235}U content was ~ 38 g and ~132 g for the low and high enrichment, the fuel cladding was a 3.734 cm stainless steel tube with a thickness equal to 0.508 mm. Since March 2012 the reactor core has 74 fuel elements and 3 FFCR with low enrichment, the type of these elements are 30/20, the total uranium content is 30% and the enrichment is 20%, the nominal uranium content is 825 g with 165 g ^{235}U.

2.3. The reactor core with 30/20 fuel [3]

The reactor core has 4 fuel elements in B ring with B1 and B4 as empty positions, the C ring has 10 fuel elements and 2 control rods, the transient rod is in C4 position and the regulating rod in C10; the D ring has 16 fuel elements and the shim and safety control rods in D1 and D10 positions; the E ring has 20 fuel elements and 4 empty positions; the F ring has 24 fuel elements and 6 empty positions and finally the G ring has 34 graphite dummy elements (the original ones from the old reactor core), and the pneumatic terminus. A horizontal cut of the new reactor core is shown in Fig. 8.

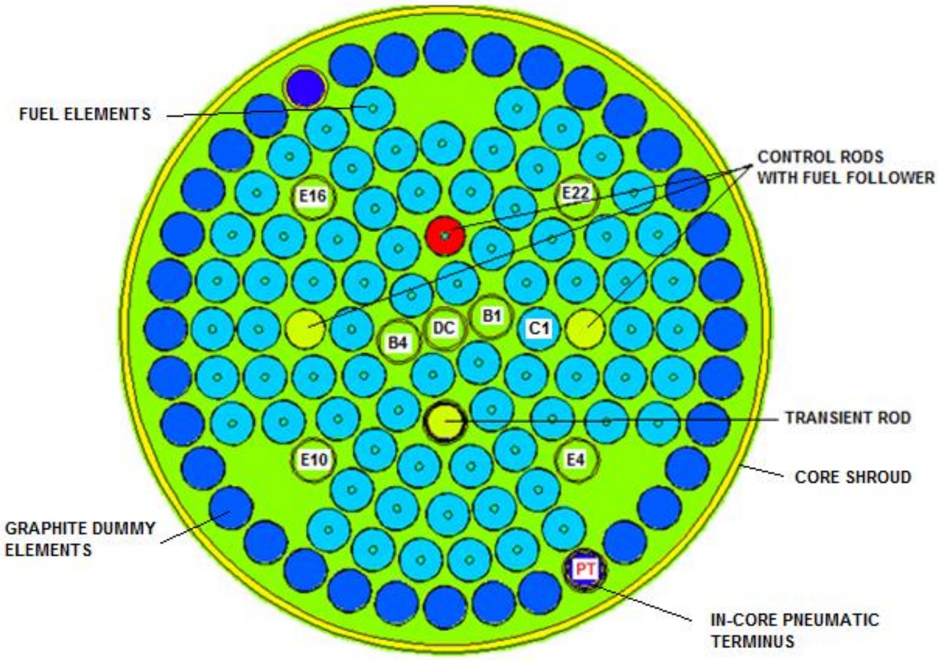


FIG. 8. The new reactor core with LEU 30/20 fuel.

2.3.1. The LEU 30/20 fuel elements [4]

The high uranium content fuel elements and FFCR's have the same form and external dimensions like the old ones. Therefore, it was not necessary to make any changes in the reactor grids. The external dimensions for the fuel elements are 75.39 cm long; the cladding is a tube with 3.7465 cm diameter with top and bottom end plugs. The fuel has a top and bottom graphite reflectors and three large pellets 12.7 cm long, 3.645 cm external diameter, the pellets has an inner perforation, fuel region itself is 38.1 cm long. In Fig. 9, an external and internal view of the fuel elements and the control rods are shown.

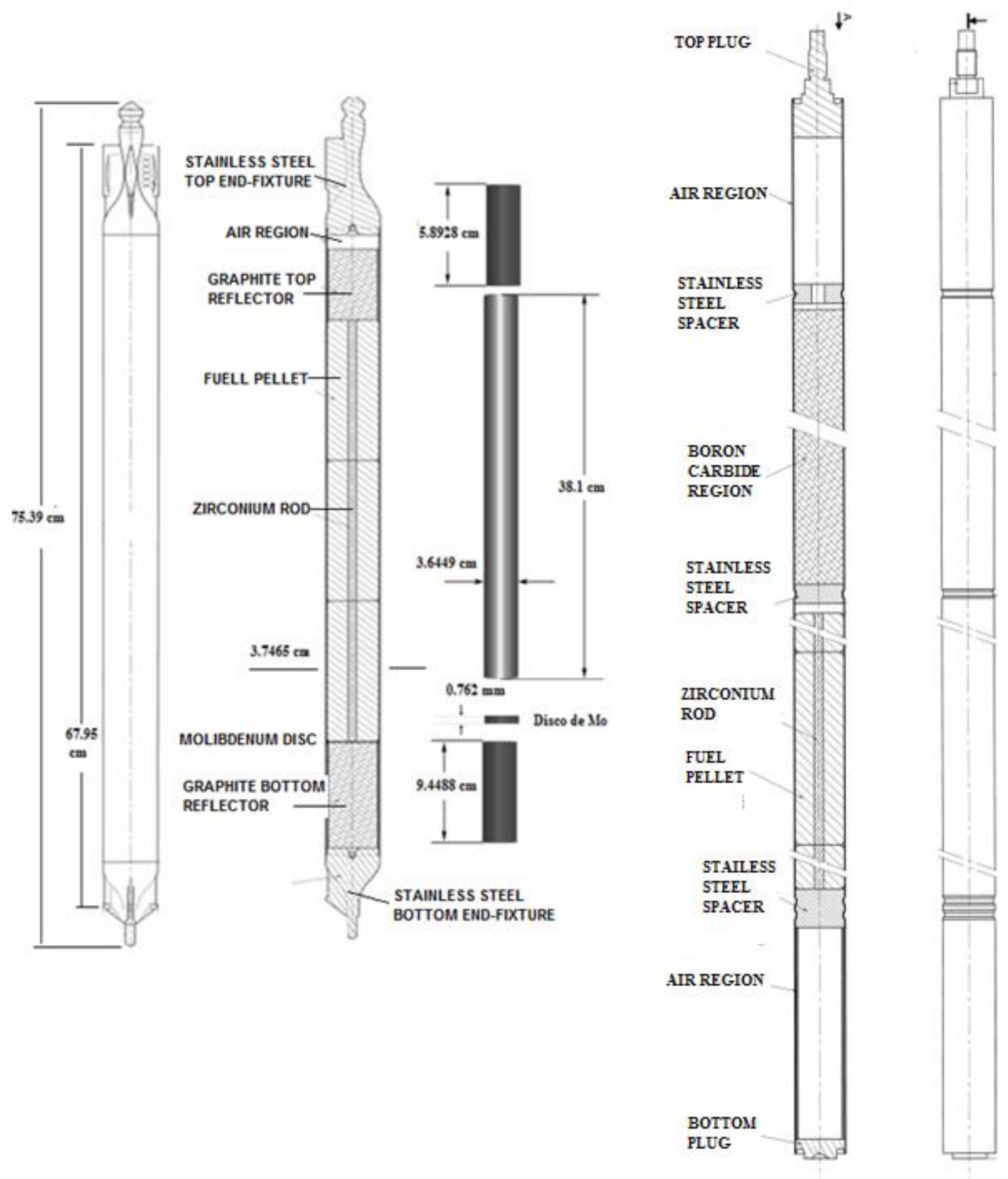


FIG. 9. External and internal view of the fuel elements and the control rods.

The fuel composition is presented in Table 1, it includes detailed contents of all uranium isotopes, natural erbium and carbon (the fuel follower in the control rods have the same composition).

TABLE 1. COMPOSITION FOR THE FUEL AND FOLLOWERS FOR THE CONTROL RODS

	Molecular weight	(g/cm^3)	Weight fraction		Molecular weight	(g/ cm^3)	Weight fraction
H	1.0079	0.0835	1.1673E-02	Er-168	167.9324	0.0171	2.3840E-03
C	12.0110	0.0212	2.9650E-03	Er-170	169.9355	0.0095	1.3250E-03
Zr	91.2240	4.8648	6.7997E-01	U-234	234.0410	0.0028	3.8545E-04
Er-162	161.9288	0.0001	1.2120E-05	U-235	235.0439	0.4213	5.8884E-02
Er-164	163.9293	0.0010	1.4300E-04	U-236	236.0456	0.0023	3.2615E-04
Er-166	165.9303	0.0214	2.9890E-03	U-238	238.0508	1.6949	2.3690E-01
Er-167	166.9320	0.0146	2.0420E-03				

2.3.2. Neutron flux calculated for some in-core experimental facilities [5]

The B1 and B4 positions are very interesting to be used as new in-core experimental facilities, they are next to the central thimble and the neutron flux in these three positions are very similar. To prepare these positions as new experimental facilities, aluminum tubes are going to be placed in these empty positions. The cylindrical containers that are used to place the samples in these positions are about 3 cm in diameter by 10 cm high.

In Fig. 10 are shown the thermal flux calculated with MCNP for the CT, B1 and B4 whilst in Fig. 11 the flux for neutrons with energy between 1.0-10.0 MeV for B1, B4 and E-16 is shown.

Position (cm)	Neutron flux (n/cm^2-s)		
	DC	B1	B4
20.95	7.813E+12	7.801E+12	7.447E+12
19.05	8.504E+12	8.595E+12	8.987E+12
17.14	1.035E+13	1.044E+13	1.036E+13
15.24	1.235E+13	1.293E+13	1.261E+13
13.33	1.426E+13	1.481E+13	1.466E+13
11.43	1.646E+13	1.668E+13	1.672E+13
9.52	1.869E+13	1.887E+13	1.899E+13
7.62	2.061E+13	2.090E+13	2.040E+13
5.71	2.232E+13	2.262E+13	2.314E+13
3.81	2.330E+13	2.511E+13	2.513E+13
1.90	2.608E+13	2.700E+13	2.668E+13
0.00	2.722E+13	2.816E+13	2.814E+13
-1.91	2.867E+13	2.935E+13	2.945E+13
-3.81	2.921E+13	3.076E+13	3.028E+13
-5.72	**2.953E+13**	**3.098E+13**	**3.129E+13**
-7.62	2.894E+13	3.009E+13	3.054E+13
-9.53	2.764E+13	2.921E+13	2.859E+13
-11.43	2.648E+13	2.810E+13	2.709E+13
-13.34	2.427E+13	2.520E+13	2.551E+13
-15.24	2.168E+13	2.310E+13	2.301E+13
-17.15	2.041E+13	2.045E+13	2.012E+13
-19.05	1.811E+13	1.891E+13	1.883E+13
-20.96	1.711E+13	1.715E+13	1.702E+13

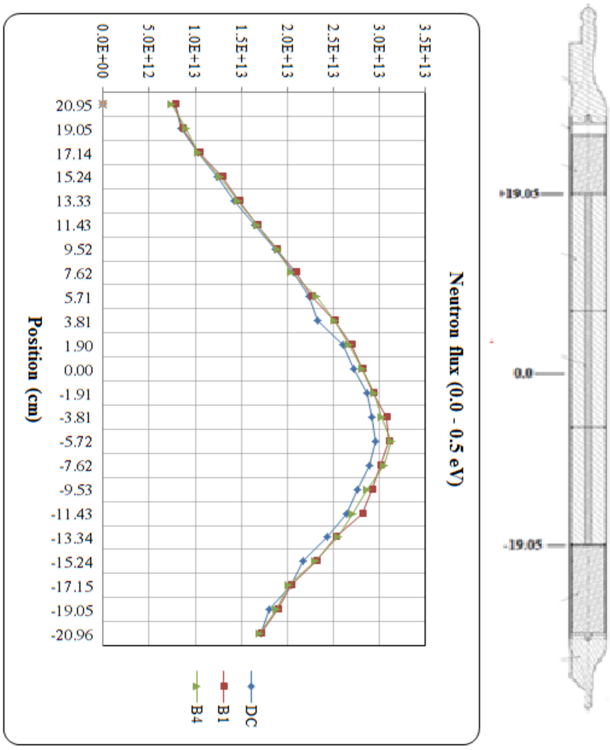


FIG. 10. Thermal neutron flux in DC, B1 and B4.

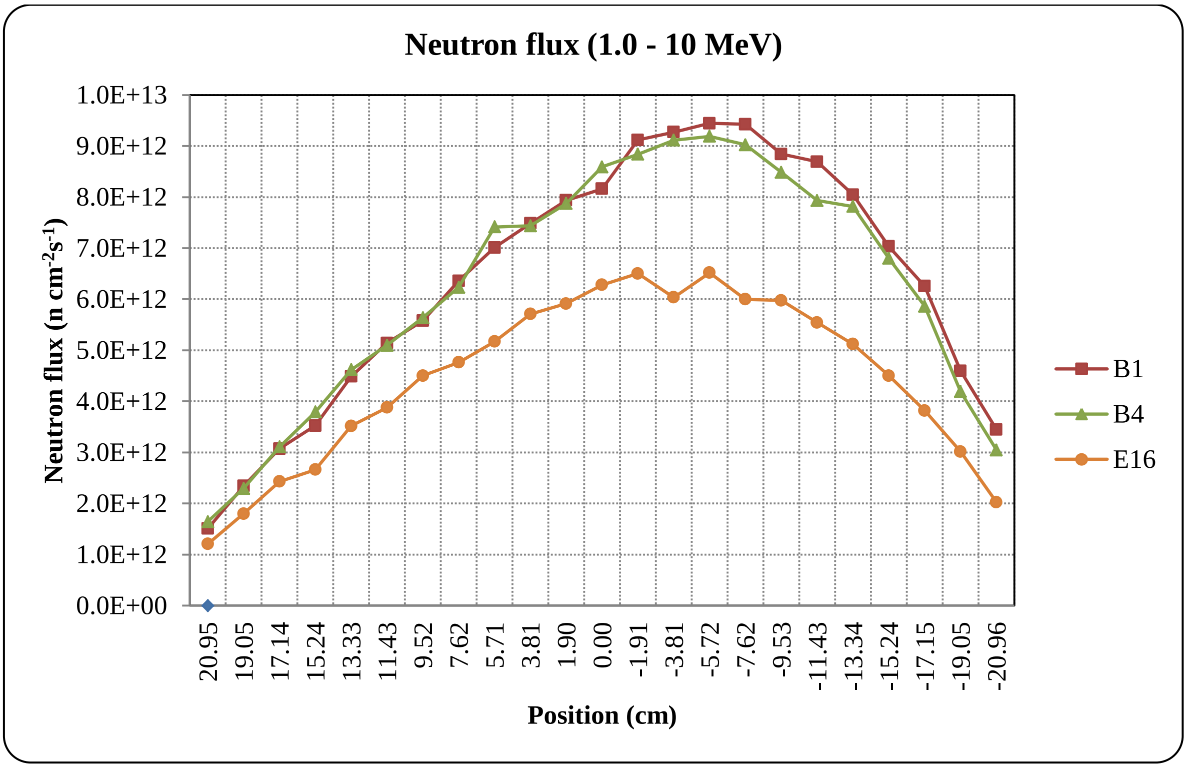


FIG. 11. Neutron flux for energies between 1.0-10.0 MeV for B1, B4 and E16.

2.4. The safety of the reactor

The safety of TRIGA reactors is based on the prompt fuel temperature reactivity coefficient and on the automatic reactor scrams; they are done if some operational conditions represent a risk for the reactor. For the TRIGA Mark-III reactors there is an additional component, the interlock system, this is close related with the movable reactor core.

2.4.1. The prompt fuel temperature reactivity coefficient [2]

The TRIGA Mark-III reactor is used for untrained personnel, for example students, under the supervision and responsibility of licensed operator, then the reactor must have inherent safety characteristics to avoid any incidents when a mishandling can introduce instantaneously all the available excess reactivity. This requirement for the inherent safety is accomplish with the large prompt fuel negative reactivity coefficient -8×10^{-5} $(\Delta k/k)/°C$.

2.4.2. Automatic scrams during reactor operation [6]

The purpose of the automatic scrams is to avoid operational conditions that could be dangerous for the reactor or to avoid the operation by a careless operator. The following automatic scrams are the most important:

- The linear channel has seven scales; the reactor operator must be aware to change from one scale to the upper one before the reactor overcome 110% in the actual operating scale.
- When the reactor power is increased and the period is smaller than 3 seconds.
- The linear and the (%) channel would initiate a scram at 1.1 MW.

2.4.3. The interlock system [6]

The interlock system is basically related with the core movement along the reactor pool, the purpose of this system is to avoid conditions that could be dangerous for the personnel or for the Lazy Susan. Some of the most important are:

- To start the reactor operation it is necessary to have a neutron source in the reactor and a minimum number the counts in the startup channel.
- The exposure room or thermal column shielding door cannot be open if the reactor core is next to one of them. To open the door in this condition will be very dangerous for the personnel (very high radiation levels will be in the reactor hall).
- The reactor core cannot be moved to the exposure room or to the thermal column if the respective shielding door is open; this condition will be very dangerous for the personnel.
- The reactor core cannot be moved to one of the pool ends if the Lazy Susan is in the down position (the Lazy Susan can be damaged).

When there is a careful operator and all the conditions are satisfied for operation, the reactor can be driven by a nominal power of 1 MW_{th} in steady-state mode (Fig. 12).

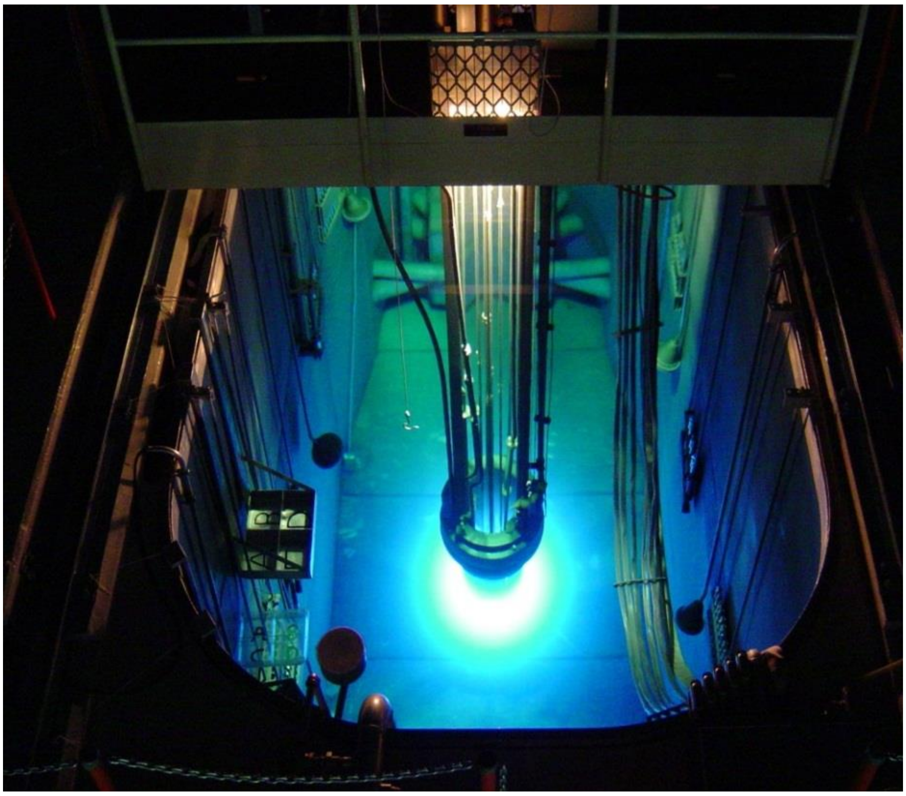


FIG. 12. TRIGA Mark-III reactor operating at 1 MW.

3. REACTOR UTILIZATION

The reactor utilization is based on demand, there is no a fixed programme, i.e. reactor operation depends on the requirements for radioisotope production, neutron activation analysis or educational activities.

3.1. Radioisotope production

The radioisotope production basically is for ^{153}Sm. The operation for this purpose is 20-24 h at 1 MW, generally every 2 weeks, but sometimes every week. The sample is Sm_2O_3 and the weight is about 10 mg and the irradiation time is 20 h to get 4 to 5 doses with about 7.4 GBq. The sample is irradiated in the central thimble, it is delivered to the personnel from the radiopharmaceuticals production plant (RPP) after about 3 h of cooling time, they take the sample to the RPP prepare the ^{153}Sm-EDTMP doses and sent them to the hospitals

3.2. Neutron activation analysis

The neutron activation analysis is used to analyse biological, mineral or environmental samples. This technique is used to determine the elemental composition of samples in qualitative or quantitative way. At present the analysis capacity is about 300 samples per year, but there is a process to improve the technique in order to get the accreditation ISO-17025 and the new laboratory construction is underway. We expect to have more customers with the accreditation and with a new homemade automatic sample changer, to be installed in the new lab.

3.3. Educational activities

We have two kind of educational activities, students that visit the reactor and several installations at ININ and students in academic programs to get a master's degree in nuclear sciences.

3.3.1. Undergraduate students

ININ as a national institution receives visits from several schools from the country, this visits are for students from high school and upper levels. They visit several installations in the Nuclear Center and one of them is always the TRIGA Mark III reactor, for these visitors we have developed a touch screen application to explain the reactor, the experimental facilities, the applications, the fission process, etc. The number of visitors per year is about 2000.

3.3.2. Graduate students

ININ has agreements with universities in the country with academic programs in nuclear sciences, the Universidad Nacional Autonoma de México (UNAM) has a master degree in Engineering in Energy and one subject is Nuclear Reactor Analysis, the Instituto Politécnico Nacional (IPN) has a master degree in Nuclear Engineering, the Universidad Autonoma de Zacatecas (UAZ) has a master degree in Nuclear Sciences and the Universidad Autonoma del Estado de México has a master degree in sciences with option in Nuclear Sciences. Students from these universities come to the reactor and do by themselves some experiments, for example: reactor operation from 0 W power to its nominal power of 1 MW_{th}, radiation measurements at several places in the reactor, control rod calibrations, etc. Figure 13 shows two groups one from UNAM and the other from UAZ.

FIG. 13. Students from UNAM and from UAZ making experiments with the reactor.

4. MAJOR ACHIEVEMENTS

The major achievements in the recent years were the change of the control console, the design and construction was made by the Department of Automation and Instrumentation, and the conversion of the reactor core from high to low enrichment.

4.1. Control console change

In November 1968 when the reactor started the operation the control console provided by General Atomics had state of the art electronics, hybrid electronic circuits, germanium diodes, electromechanical relays, etc. Nevertheless, the advances in electronics make obsolete some components and it was necessary to introduce some changes. In 1990 a project was started to develop a new control console based on the following premises:

- The development must be made at ININ,
- To use commercially available components as much as possible,
- The control must be made with a computer aid.

In 2001 the Comision Nacional de Seguridad Nuclear y Salvaguardias (the regulatory body) approved the installation of the new control console. The installation was done in four steps: the first one was to make experimental measurements with the old control console in all the licensed operational modes (steady state operation, manual or automatic, square-wave and pulsing mode), the collected data were the reference for the new control console; the second step included the removal of the old console and the installation of the new one; the third step was to test the control rod movements and in the fourth the experiments from the first step were reproduced in order to compare the data with the old data. When it was demonstrated that the new data were almost the same to the old one then the regulatory body authorize the reactor operation with the new control console. See (Fig. 14).

FIG. 14. The old and the new control console.

4.2. Reactor conversion from high to low enrichment

4.2.1. Agreement for the reactor conversion

After several years of failed negotiations between the Mexican government and the Department of Energy from the United States of America (DOE), an agreement was reached with the aid of the International Atomic Energy Agency (IAEA) to make the reactor conversion from high to low fuel enrichment. The agreement established that Mexico will return all the high enriched fuel (26 in the reactor core and 3 FFCR, 25 fresh fuel and 3 fresh control rods) and the DOE agreed to deliver to the IAEA 116 fresh fuel LEU 30/20, 6 control rods with fuel follower and 3 instrumented fuel. The IAEA later made the fuel transfer to the Mexican government through ININ. Besides, the DOE agreed to pay all the transportation costs and to pay studies to GA to design and evaluate the new reactor core. The new reactor core design was made by ININ's personnel and GA made the evaluation/review studies for it.

4.2.2. The design of the new reactor core [7]

The first step was to make a reactor core model, for MCNP5-1.6 code, with 85 fuel elements, 4 control rods and an empty position for an in-core radiation detector. The calculated reactivity excess was too high and then it was started a search to find a reactor core with appropriate reactivity excess and shut down margin. In Fig. 15a is shown the core with high and low enrichment fuel, Fig. 15b shows the full core with 30/20 and Fig. 15c shows a core with 15 fuel empty positions in F ring, it has a good reactivity excess and shut down margin. The empty positions in the F ring were not attractive to be used as a new incore experimental facilities, the neutron flux in them will be low compared with the neutron flux in central thimble. A process was started to find a reactor core with some empty fuel posititions with high neutron flux with the pourpose to use them as new incore facilities. The proposed solution was to have 2 empty positions in B, 4 in E and 6 in F ring; the positions B1 and B4 have a neutron flux as high as the central thimble. In Fig. 7 the final reactor core is shown, this proposal was aproved by the Reactor Committee and by the national regulatory

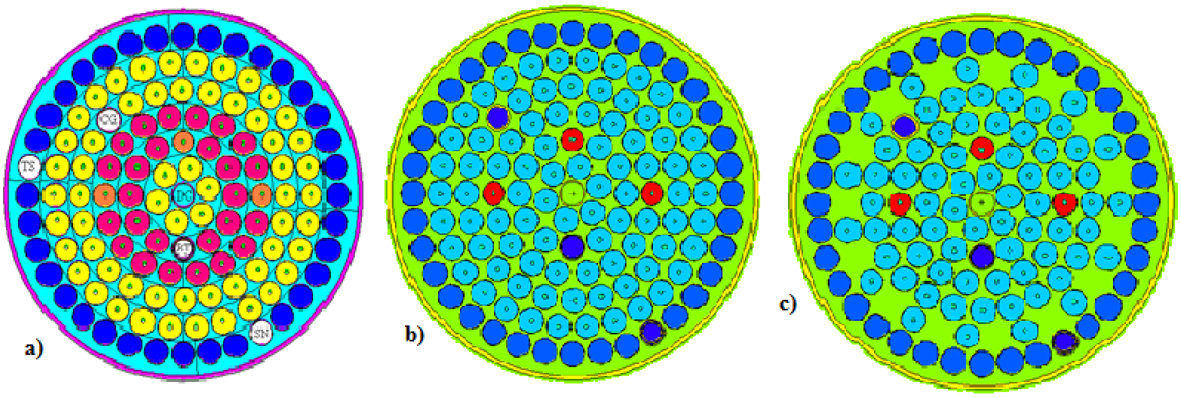


FIG. 15. Reactor core models used to find the final core; a) the core with high (red) and low (yellow) fuels, b) full core with 30/20 fuel and c) a core 15 empty positions in F.

5. FUTURE PLANS AND CHALLENGES

The following are the foreseen activities to increase the reactor utilization and to use the new in-core experimental facilities: a) new radioisotopes production, b) life extension studies for Laguna Verde Nuclear Power Plant and c) increase the use of the neutron activation analysis. Additionally there is a reactor modernization project, the main updates are for: a) the instrumentation and control, b) ventilation system, c) cooling system, d) neutron activation labs, e) radiological monitoring system, f) new graphite elements fabrication and g) interim dry storage for the low enrichment spent fuel.

5.1. Activities to increase the reactor utilization

5.1.1. New radioisotopes production [8]

There are plans to produce ^{99}Mo and ^{131}I by activation; the B1 and B4 positions are going to be used for that purpose. The samples are going to be TeO_2 and MoO_3 (natural or enriched), the irradiation time could be about 120 h and the weight about 50 g in each position, 100 g of MoO_3 in total (the estimated activity with the natural MoO_3 is about 11 GBq ^{99}Mo / g MoO_3). The foreseen activities are

- Experimental irradiation conditions; target sizes, irradiation and cooling time, irradiation capsules, activated target handling, etc.,
- Experimental program in the TRIGA Mark III Reactor, to evaluate the activation production capacity, using natural and enriched MoO_3 and TeO_2,
- Cost – benefits studies for production with the TRIGA reactor.

5.1.2. Life extension studies for LVNPP

Laguna Verde site has two BWR reactors, it is located in Veracruz state; the first reactor started its operation in 1990 and the second one in 1995. Comisión Federal de Electricidad (CFE) is the owner and operator of both units. There is a joint project for the life extension studies between CFE, ININ, CONACYT(national council for science and technology) with the technical support from CSK-Belgium. The foreseen activities are:

- Neutron spectrum calculation for the new irradiation facility E-16.
- Experimental neutron spectrum measurements for neutrons with energy higher than 1 MeV.
- Design and construction of the irradiation rig to irradiate steel specimens at ~ 290°C.
- Steel specimens irradiation for an equivalent to 10, 20, 30, 40, 50 and 60 years of full operational years.

5.2. Reactor modernization programme

There is an active technical cooperation project with the IAEA for the modernization of several reactor installations. The most important expected outputs include a new control console, the uprate of the cooling system to 1.5 MW, the ventilation system, the new lab for neutron activation analysis, the modernization of the radiation monitoring system, etc.

5.2.1. New control console design and construction

The Departamento de Automatización e Instrumentación from ININ, will be responsible for the design and construction of a new control console, the personnel from the reactor will be responsible to test the new console and to make all the paper work to get the license, from the regulatory body, to use it. The main characteristics are:

- Distributed control using PLC technology;
- An option for the control rod calibration (at present it is necessary to install an additional computer for this purpose);
- The installation of new detectors for the power channels;
- An option for thermal power measurement;
- A new desk with ergonomic design.

5.2.2. The uprate of the cooling system

The new cooling system will have the capability to cool down 1.5 MW reactor power. The main changes will be:

- A new cooling tower.
- Pumps replacements for the primary and secondary cooling systems.
- Flow meters for the primary and secondary cooling systems.
- Control to adjust the cooling capacity to the reactor power.

5.2.3. Ventilation system

The pneumatic control for the ventilation system is going to be replaced for an electronic one.

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UPGRADING OF THE INSTRUMENTATION AND CONTROL OF NUCLEAR REACTOR IAN-R1

J. SANDOVAL

Servicio Geológico Colombiano
Diagonal 53 No.34-53
Bogotá D.C.
Colombia

E-mail: jsandova@sgc.gov.co

Abstract.

The associated Instrumentation & Control of the Research Nuclear Reactor IAN-R1, located in Colombia, was updated on the year 2012, as a direct result of the initiative by the Colombian Government represented by the Colombian Geological Survey (Servicio Geológico Colombiano). The result of the conversion from Highly-enriched MTR Nuclear fuel into Low-enrichment TRIGA Nuclear fuel guarantees a nuclear reactor that can be operated for several years. The present document presents the Current Technical Status (status of available infrastructure and utilization capabilities, including staff) of the reactor, its success stories, major achievements, and future prospects.

1. BRIEF HISTORY

The reactor was originally designed and built by Lockheed Nuclear Products in 1965 as a small, 10 kW facility using aluminum plate-type, highly enriched fuel (MTR). It was donated to the country under the Atoms for Peace Program led by the US President Dwight D. Eisenhower. This reactor was operated and maintained by the Institute of Nuclear Affairs (IAN) in Colombia and was set to critical on February 20th 1965.

This research reactor is a pool type TRIGA Reactor with concrete shielding and two beam ports, cooled by light water and uses graphite as its reflector [1].

In 1992 the International Atomic Energy Agency (IAEA) sponsored a series of projects in order to upgrade the Radiological Protection Program and also the Reactor's Instrumentation and Control systems because its parts were obsolete, was not easy to found spare parts in the market and the failure rate were frequent [2].

The nuclear activities in Colombia were interrupted in 1997 with the extinction of the Institute of Nuclear Affairs (IAN). In this year, eight fuels elements were removed from the reactor core to kept TRIGA IAN-R1 Reactor in a secure subcritical condition. It was brought into an extended shutdown condition, and the core was converted from HEU fuel plates to LEU TRIGA Fuel ($UZrH_{1.6}$) enriched to 19.7 wt%. The same year, the nuclear reactor and its facilities were incorporate to the Colombian Institute of Geology and Mineralogy – "INGEOMINAS" of the Ministry of Mine and Energy, which is currently known as the Colombian Geological Survey (Servicio Geológico Colombiano) [3-5].

The reactor was put in extended shutdown from 1998 until 2005 due to licensing issues, and has been operating for short periods of time since then in order to train personnel with the support from the IAEA, the Atomic Institute of the Austrian Universities and courses held in Brazil and Argentina.

In 2012 the Nuclear Research National Institute (ININ) from México upgraded the instrumentation and control (I&C) once again, introducing concepts like independent systems, redundancy, TCP/IP communications, as well as BUS and CAN OPEN industrial communication protocols. This project was financed by the "Agencia Nacional de

Hidrocarburos (ANH)” and the “Departamento Administrativo de Ciencia, Tecnología e Innovación (Colciencias)”.

The main characteristics of the new I&C are: Function Logic separate using distributed control and modularity, direct wiring system to avoid performing security functions through software, use of the TCP/IP standard to achieve systems interconnectivity, good performance of the HMI, and use of open source codes for future updates.

2. CURRENT TECHNICAL STATUS

2.1. Available infrastructure [6]

2.1.1. Instrumentation and Control Technical Specifications

The nuclear reactor has a main console and associated instrumentation in order to guarantee that its systems are working correctly. This console provides visual and audio signals of the different alarm systems, and provides the necessary tools to control the different parameters in the Reactor and its associated systems for its safe operation (Fig. 1).

FIG. 1. Nuclear Reactor Console.

The instrumentation and control (I&C) of the Reactor is shown in Fig. 2, its Systems and Components are described as follows:

- *Redundant Control System*

Manually and automatically controls the motors that drive the control rods in and out of the reactor, determines the position of control rods, controls the interlocks for reactor start-up, and also determines the reactor power and reactor period through the nuclear channels.

- *Protection System*

Its function is to safely shutdown the nuclear reactor in case of pre-established failure scenarios.

- *Instrumentation Supervisión System*

The system collects data from auxiliary systems such as: Heat exchanger, reactor pool temperature, and radiation area monitors.

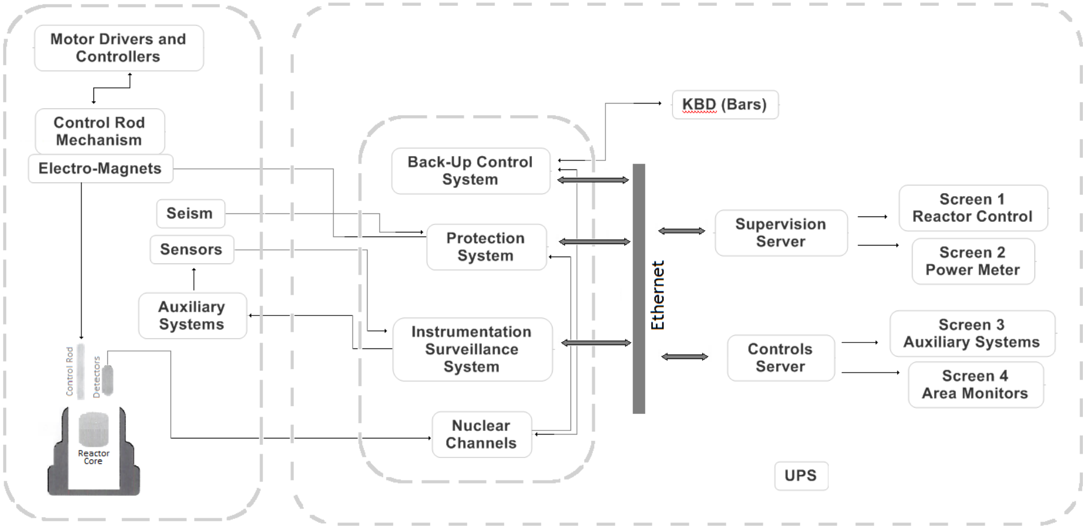

FIG. 2. I&C Blocks diagram for the Research Reactor IAN R-1.

- *Human Machine Interface (HMI)*

HMI displays all the variables from the Control System and Auxiliary Systems, displays the different alarms and SCRAM mechanisms.

2.1.1.1. Instrumentation and control characteristics

- Logic separation of functions by applying distribution control and modularity concepts.
- Employs direct wiring for the Protection System instead of software.
- Uses Ethernet to accomplish the interconnectivity of nuclear systems and reduces wiring to obtain signals from the reactor to the main console.
- High resolution monitors for the HMI to display operational parameters and reactor controls.
- Industrial Servers which are easily upgraded and maintained.
- HMI programmed in JAVA.
- Capacity to expand input/output signals.
- Replacement parts are easily accessible in the market.

2.1.1.2. Reactor Control System

The Nuclear Reactor IAN-R1 uses three control rods and two security rods. The control rods are connected to individual drive motors attached on the top section of each control rod.

The reactivity of the reactor is controlled through the interaction of the following Systems and Equipment:

Redundant Control System (RCS)

This system is designed for redundancy and independence of components through different security barriers so the Protection System, Control System and Supervision System of the instrumentation are not in contact with other signals through the use of optocouplers. The Control System acts independent of other systems.

The RCS controls the nuclear reactor with commands/inputs from the operator (Fig. 3). It has a PLC with redundant modular architecture with an industrial platform that provides automatic redundancy in order to guarantee availability and security in the process.

The main component of this system is the second back-up PLC with the same configuration as the primary controller. The RCS is able to detect failure of the main controller and associated modules in order to immediately switch control to the back-up PLC and its modules.

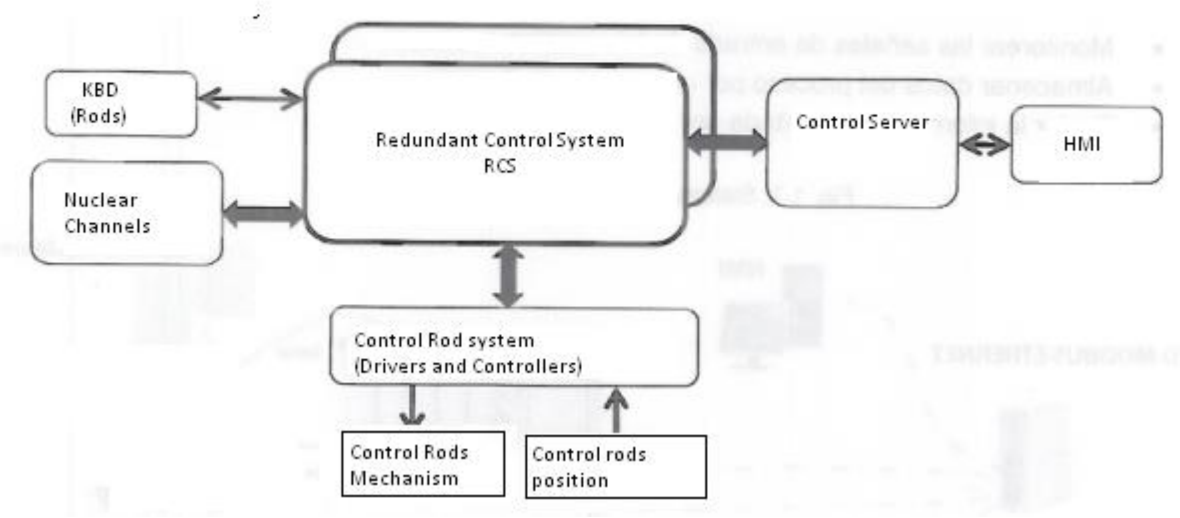

FIG. 3. Redundant Control System Diagram (RCS).

Redundant control system functions:

- Controls the position of control rods by operator input from the Control Board on console.
- Controls Reactor Power when on automatic operation mode.
- Monitors input signals from nuclear channels.
- Stores process data for up to two hours.
- Sends data to the HMI.

Control Rod Mechanism

The Control Rod Mechanism is in charge of positioning the control rods in the reactor core through operator commands using the HMI. Communication between this Mechanism and the RCS is carried through the CAN OPEN Protocol.

The IAN-R1 Research Reactor has three mechanisms for control rod positioning which use drive motors for its displacement. This Control Rod Mechanism consists of three driver-controllers which are mounted on a humidity-proof gabinet nema 12. (Fig. 4)

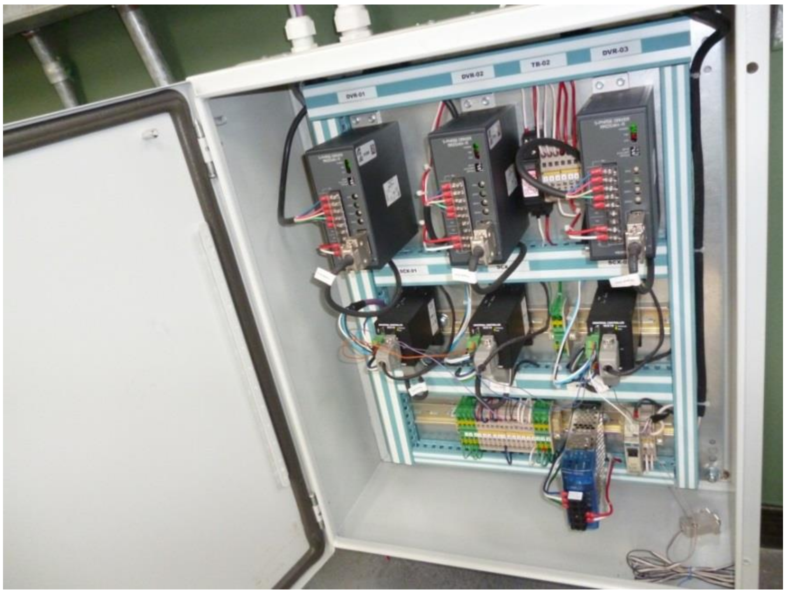

FIG. 4. Driver-controllers of the control rod mechanism.

Control Board

The manual operation of the reactor is handled through the Redundant Control System, it employs a board connected to the main console. This board consists of a key-hole, SCRAM button and three different buttons that control each control rod separately.

FIG. 5. Control board.

Nuclear Channels

The reactor’s I&C consist of three measurement channels for neutron and gamma fluxes, two wide-range NM1000 channels and a security channel NP1000 fabricated by General Atomics. Each channel operates independently of the other.

Human Machine Interface (HMI)

The HMI consists of the necessary hardware and software for reactor control. The software corresponds to the system “HMI-IANR1 ver 2012 (Sistema de Control del Reactor)”. The operator interacts with the system through four LCD monitors where the graphical user interface (GUI) is displayed (Fig. 1).

The system is accessed with a password and a key to identify the type of user as operator or administrator, each having different privileges and/or restrictions.

2.1.1.3. Protection System (PS)

The reactor’s Protection System is automatic and independent from the other systems. It consists of two solid-state circuit boards and two combinational logic boards that operate simultaneously and provide the Protection System with a redundant architecture (Fig. 6).

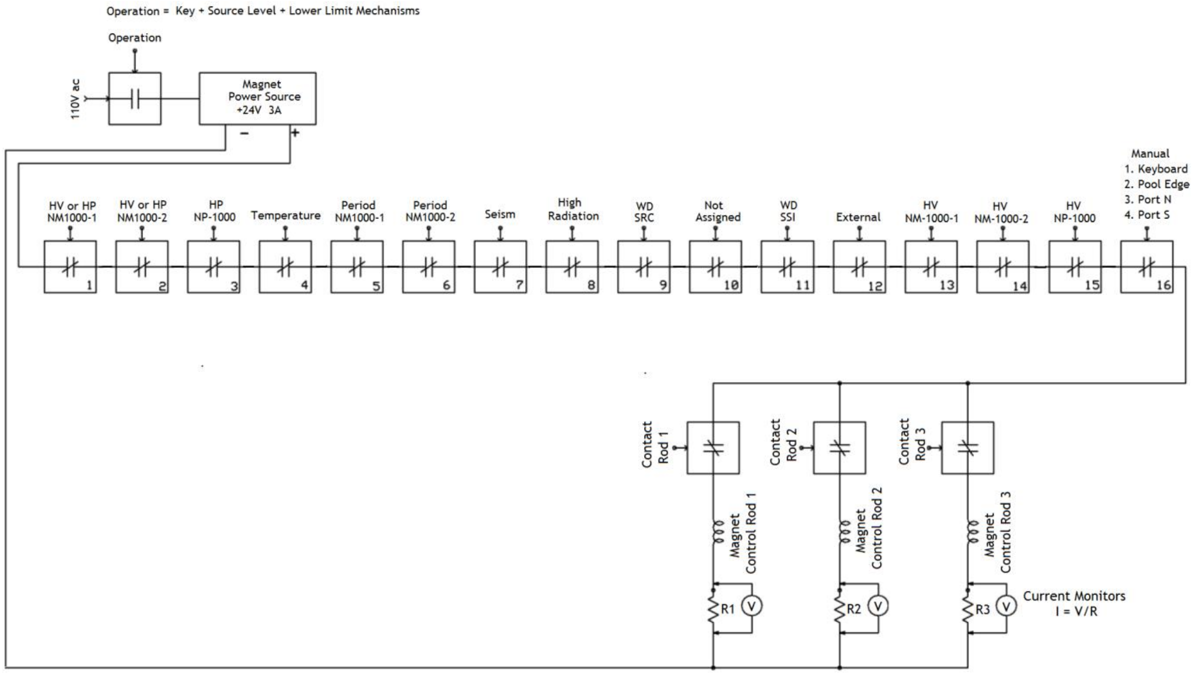

FIG. 6. Protection System.

In order to activate the Protection System a permission signal is required, this signal is obtained only after the control rods are lowered, the appropriate key is inserted on the Control Board and the Source level is appropriate.

The Protection System inserts control rods into the reactor in case of current-shortage. The control rods are attached to electro-magnets that hold them in position, when no current flows through then the magnets lose their ability to hold the rods and they fall into the reactor due to gravity. Different security signals are used to cut-off the current that feed the magnets attached to the control rods in case of emergency, this shortage in current causes the rods to fall into the core and stop the chain reaction in the reactor core.

2.1.1.4. Instrumentation Supervision System

This system constantly monitors the instrumentation the process variables, during operation and during stand-by. It consists of a PLC equipped with data acquisition and communication boards. The data is transmitted through the Ethernet bus (Fig. 7)

Its functions are the following:

- Reads process variables 10 times per second.
- Stores the history of the processes for the last two hours.
- Deactivates the "WatchDog" in case a process fails.

The ISS commands are the following:

- Ask for state of variables
- Ask for ISS state
- Ask for history data from 1 s to 7200 s

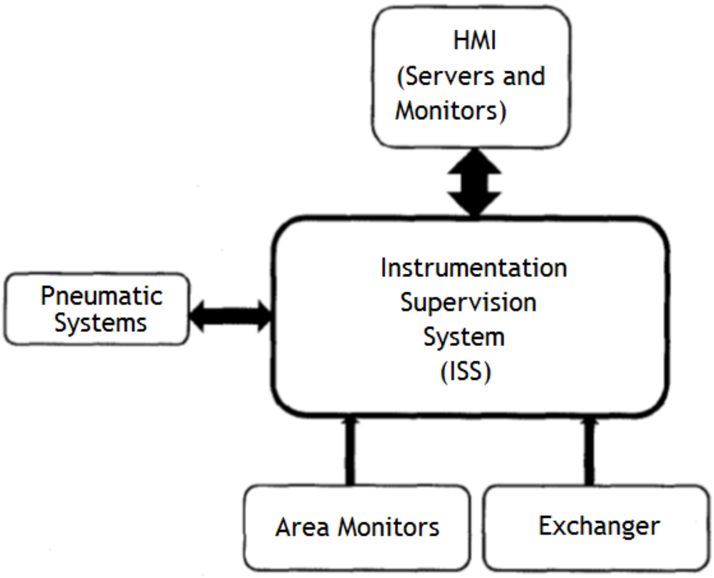

FIG. 7. Instrumentation Supervision System (ISS).

2.1. Utilization capabilities

The Nuclear Reactor IAN-R1 is capable of operation and is going currently going through the licensing process. The TRIGA core and peripheral systems such as the Water Treatment System, Cooling System, and Radiological Protection Systems have not operated for prolonged periods of time through its years (Fig. 8).

The irradiation facilities consist of two pneumatic systems for in-core irradiation and irradiation on its vicinity. There are also grids for irradiation that can be placed in desired positions around the core.

The Colombian Geological Survey has laboratories for Neutron Activation Analysis and Fission Tracks.

The facility has different Physical Security and Access Control mechanisms which are constantly evaluated by the regulatory agency (Mines & Energy Ministry) and the IAEA.

FIG. 8. Nuclear Reactor IAN-R1.

2.2. Reactor staff

The regulatory agency in Colombia requires a minimum of four staff members for the correct operation of the nuclear reactor. These members consist of a Supervisor, operator, Radiation Protection Officer and Maintenance Engineer [7]. Currently the facility has a certified operator and supervisor, the Radiation Protection Officer is going through a certification process, and the maintenance engineer is in training.

3. APPLICATIONS AND UTILIZATION

Before 1998 the reactor had been used for irradiation purposes in Neutron Activation Analysis, delayed neutrons and radioisotope production (^{198}Au, ^{82}Br, La^{140} and P^{32}) [2].

The current projects for the reactor after licensing will be those of Neutron Activation Analysis and Fission Tracks.

4. SUCCESS STORIES, MAJOR ACHIEVEMENTS

The reactor was set to critical after it was close to being decommissioned because the Colombian Government decided to close the “Instituto de Ciencias Nucleares y Energias Alternativas (INEA)”, entity which was in charge of the reactor at the time.

After INEA was closed the reactor personnel was fired, then it was possible to train an operator and a supervisor of reactor, a few short-term licenses where obtained during the following years but no actual research was conducted.

In order to prolong the reactor’s life its I&C was upgraded, the fuel was converted from MTR HEU Plates into LEU TRIGA fuel. This upgrade in instrumentation wasn’t manufacturer specific, making it easier to find spare parts and replacements in case of component failure [6].

5. FUTURE PROSPECTS

The purpose of the Colombian Geological Survey (Servicio Geológico Colombiano) is to continue training personnel and use the reactor for research purposes.

Licensing work is being done in order to operate the Reactor for periods of five years and use it to irradiate geological samples by employing Neutron Activation Analysis techniques, and fission tracks; also for the production of radioisotopes and other experiments.

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