AGEING MANAGEMENT AND REFURBISHMENT OF GHANA RESEARCH REACTOR-1(GHARR-1)

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ABSTRACT

The Ghana Research Reactor-1 (GHARR-1) Facility is a Miniature Neutron Source Reactor with a rated power of 30 kW. GHARR-1 was installed and attained criticality on December 17, 1994 and commissioned on 8th March, 1995. It has since been in operation. The routine practices and operational procedures have been set out with clear emphasis on ageing management programme at the facility. Some electronic components are changed regularly during maintenance sessions and keeping to regular purification of the reactor and pool water to mitigate against corrosion. This paper outlines the ageing management programme and mitigation practices, strategies for ageing management; periodic safety reviews, consideration of ageing during design, design features for components and unit replacement, top beryllium shim addition, and succession planning. Information sharing with other operating organizations is one of the means considered by GHARR-1 to attain excellence

1.0 INTRODUCTION

1.1 DESCRIPTION OF GHANA RESEARCH REACTOR-1 (GHARR-1)

The Ghana Research Reactor-1 (GHARR-1) is a commercial (MNSR) reactor similar to the Canadian SLOWPOKE in design [1]. It is a 30 kW tank-in-pool reactor, producing a peak or maximum thermal neutron flux in the core and its inner irradiation channels of 1×10^{12} ncm^{-2} s^{-1}. The reactor is designed to be compact and safe and it is used mainly for Research and Development in reactor and nuclear engineering, neutron activation analysis, production of short-lived radioisotopes, human resource development for Ghana's nuclear programme and for education and training. It is cooled by natural convection and moderated with light water.

The reactor complex contains 5 major components. These are the reactor assembly, control console, auxiliary systems, irradiation system and the pool containing light water.

The reactor assembly consists of the reactor vessel which contains the reactor core, beryllium (Be) reflector, small fission chambers for detecting neutron fluxes, 1 central cadmium (Cd) control rod and its drive mechanism, and thermocouples for measuring inlet and outlet temperatures of the coolant. The reactor vessel is a cylindrical aluminium (Al) alloy container, 0.6 m in diameter and 5.6 m high. The container, which is built in 2 sections, is suspended in a stainless steel-lined water pool surrounded by reinforced concrete.

The core consists of fuel elements, which form a fuel cage. The cage is inside an annular beryllium reflector and rests on a lower beryllium reflector plate. The volume of the vessel is 1.5 m^3. The fuel elements are all enriched uranium-aluminium (U-Al) alloy extrusion clad with aluminium. They are arranged in 10 multi-concentric circle layers at a pitch distance of 10.95 mm. The element cage consists of 2 grid plates, 4 tie rods and a guide tube for the control rod. Screws connect the 2 grid plates and 4 tie rods. The total number of lattice positions is 354 and the number of fuel elements is 344. The remaining positions are occupied with 6 dummy aluminium elements. There are 5 inner irradiation tubes installed within the beryllium annulus. Five outer irradiation tubes are also installed outside the beryllium annulus. Figures 1 below shows the cross sectional view of the GHARR-1 core.

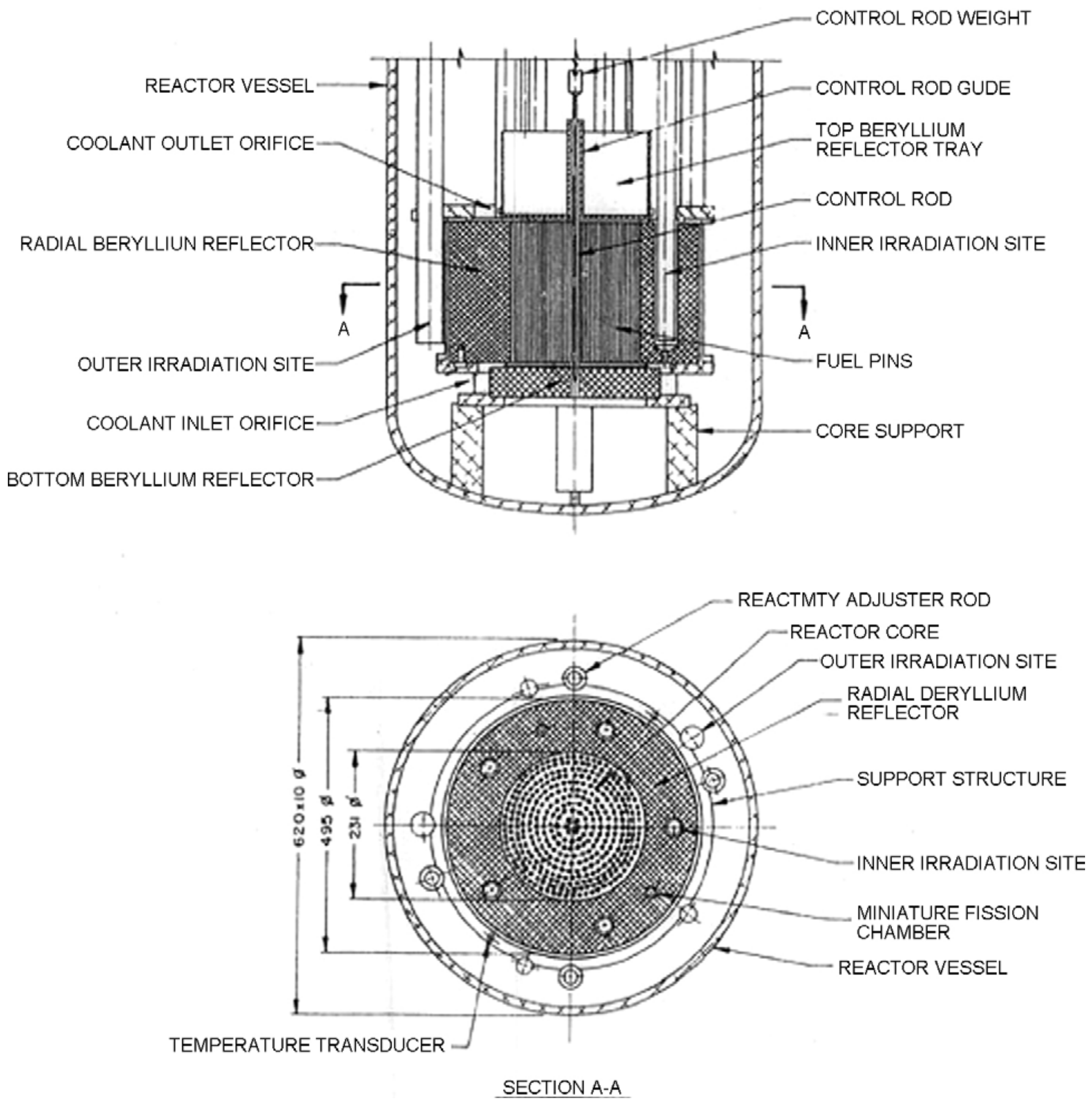

Figure 1 : The cross sectional view of GHARR-1 core

The reflector of the MNSR reactor is made of metallic beryllium. It plays a role of reflecting and moderating the neutrons leaked out from the reactor, hence maintaining peak thermal neutrons flux in the beryllium reflector containment. This is beneficial to obtaining higher thermal neutron irradiation flux under lower reactor power. The side reflector is annulus, its inner diameter being 231 mm, outer diameter 435 mm, and height 238.5 mm. The bottom beryllium reflector that supports the core is a disc, its diameter being 290 mm, thickness 50 mm. The top beryllium reflector is composed of a group of semicircular beryllium shims with different thickness, their diameter being 243 mm. These beryllium shims are used to compensate the reactivity loss caused by fuel burn-up and samarium poison. The annulus and lower reflectors are spaced to form the lower orifice, which controls water flow through the core. The top plate of the core and annulus are spaced to form the upper orifice. The reactor is designed to have self-limiting power excursion characteristics. Only one control rod is at the centre of the reactor core. A fail-safe principle is adopted in the design of the reactor control system. A single cadmium rod is used for regulating the power level, compensating for fuel consumption, startup and shutdown of the reactor. The control rod drive mechanism is mounted on the top plate of the reactor vessel.

The control console consists of the reactor control system, the radiation monitoring system readouts, monitoring panel of auxiliary systems and power supply system of the console. There are two (2) control modes for the reactor. In the first mode, the start-up or shutdown of the reactor is controlled manually by the operator and in the second mode; the reactor is controlled automatically by either the operator or the computer.

The pool is designed in accordance with industrial building standards. Its inside diameter is 2.7m, depth below ground is about 6.5 m and the wall thickness is 0.4 m. The pool is made of reinforced concrete and lined with stainless steel. The reactor incorporates several auxiliary systems. For example two purification systems for the reactor vessel water and the pool water are used for controlling the water quality. The rate of electric corrosion reduces to the lowest level provided the reactor water quality is maintained at specific resistance of 5×10^5 Ω-cm - 1×10^6 Ω-cm and the pH controlled to be 6.0 ± 0.5. A reactor gas purge system is employed to pump out and purge the gas accumulated at the top space of the reactor vessel. There are monitoring systems for water temperature and dose-rate levels. Dose-rates at the top of the reactor vessel, the working area of the reactor hall and the reactor water deionizer column are detected and measured on the control console. There are other auxiliary systems for the utilization of the reactor such as the pneumatic transfer systems. The system known as type A is suitable for medium and long time irradiation periods. Type B, a multifunction capsule transfer system has four irradiation sites.

The core region of GHARR-1 is located 4.7 m under water close to the bottom of a watertight

reactor vessel. The quantity of water is 1.5 m^3 in the vessel, which serves the purpose of radiation shielding, moderation and as primary heat transfer medium

The water-filled reactor vessel is in turn immersed in a water-filled pool of 30 m^3.

Cold water is drawn through the inlet orifice by natural convection fig. 2. The water flows past the hot fuel elements and comes out through the core outlet orifice. The hot water rises to mix with the large volume of water in the reactor vessel and to the cooling coil. Heat passes through the walls of the container to the pool water. A diagrammatic representation of the heat transfer mechanism is represented in fig.2.

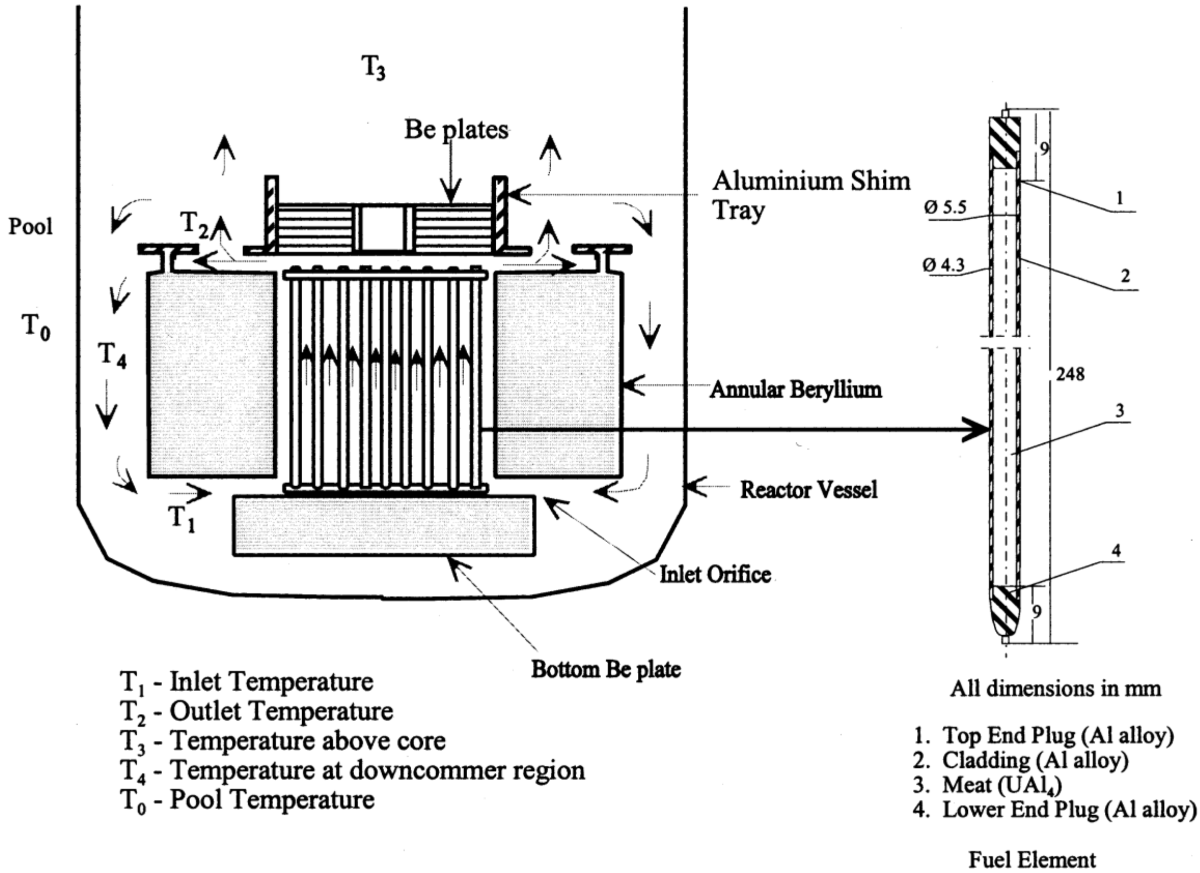

Figure. 2 Schematic diagram of the coolant flow pattern

2.0 AGEING MANAGEMENT PROGRAMME OF GHARR-1

Ageing management is defined according to IAEA specific safety guide SSG-10 as engineering, operation, and maintenance strategy and actions to control within acceptable limits the ageing degradation of structures, system and components (SSCs).

Ageing management includes activities such as repair, refurbishment and replacement of SSCs, which are similar to other activities carried out at a research reactor in maintenance and testing or when a modification project takes place. Effective management of ageing requires the use of a methodology that will detect and evaluate ageing degradation as a consequence of the service conditions, and involves the application of countermeasures for prevention and mitigation of ageing degradation [13].

The Atomic Energy Act 204 section 8 of 1964 (now amended by ACT 588, 2000) established the Ghana Atomic Energy Commission (GAEC) to undertake training, research and isotope production. The Chairman of the Board and the Director of the Institute are appointed by the Chairman of GAEC.

The National Nuclear Research Institute (NNRI) is the Operating Organization of GHARR-1 through the Nuclear Reactors Research Centre (NRRC). The Radiation Protection Board (RPB) which was established by the legislative instrument LI 1559 of PNDC Law 308 is the Regulatory Body that has issued license for the operation of the reactor amongst other regulatory activities.

The Reactor Manager, the Reactor Safety Committee and the Radiation Safety Committee report to the Director of the Institute.

The scope of programme for GHARR-1 ageing management focuses on the management of physical and non physical ageing of SSCs. Ageing is as a general process in which the characteristics of SSCs gradually change with time or use. Research reactors experience two kinds of time dependent changes:
(1) Degradation of SSCs (physical ageing), i.e. gradual deterioration in their physical characteristics;
(2) Obsolescence of SSCs (non-physical ageing), i.e. their becoming out of date in comparison with current knowledge, standards and technology.

The following are major components of ageing management programme put in place to mitigate ageing of SSCs of the GHARR-1 facility and these are summarized under operational safety approach….

i. Operational Procedures

ii. Maintenance Procedures

iii. Periodic Testing and Inspection Procedures

iv. Radiation Protection Procedures

v. Utilization and Modification Procedures.

The operation and maintenance (O&M) group are trained to carry out corrective and preventive maintenance on the facility to ensure smooth operation of the reactor. The maintenance programme include; daily testing and inspection, weekly and annual general maintenance.

Some specific operational activities carried out by (O & M) were:

i. Reactivity and critical (core) management

ii. Core thermal safety

iii. Safety of experiments

iv. Repair actions

v. Modification of existing systems or components

vi. New installations

vii. Manipulation of special components and radioactive materials

viii. Human surveillance of equipment and personnel

ix. Inspection programmes

x. Purification and analyses of pool and reactor water

xi. Steps of approval for different safety related actions (replacements, repair, modifications and new installations)

Other regulatory activities include

- Inspection
- Monitoring & Assessment
- Renewal of Operating License

3.0 OPERATIONAL SAFETY APPROACH AND MITIGATION PRACTICES

Three different sessions of beryllium plate addition of 9 mm thickness have been performed to compensate for reactivity loss due to Samarium poisoning and fuel burn up. An aluminium tray on top of the core is used for Be shim addition to compensate for loss of excess reactivity. The top reflector is of variable thickness and assembled by stacking semi-circular plates within an aluminium tray. It is composed of a group of semi-circular beryllium shims with internal diameter of 243 mm.

Long-term reactivity control is exercised by periodically increasing the thickness of this reflector to compensate for reactivity loss caused by fuel burn-up and samarium poison. Under normal operating conditions of the reactor, the top shims need to be added less frequently than once every one and half years based on worth curve of GHARR-1 Beryllium Shim Pieces. The maximum thickness of top shims is 109.5 mm for a cold clean reactor, which is equivalent to 18 mk. In addition to the initial excess reactivity of the core, the presence of the shims ensures that the core life of the reactor fuel elements shall be longer than 10 years. So far the total thickness of Be shim added is 9 mm (3 of 3.0 mm thickness).

The reactor and pool water measurement are carried out every Monday in order to detect clad failure as early as possible. It is expected that fission products such as $^{131-135}I$, ^{90}Sr, ^{95}Zr, ^{95}Nb, ^{137}Cs, ^{140}Ba, ^{140}La, ^{85}Kr, ^{133}Xe and ^{135}Xe will be transferred through the failed clad to the reactor. Table 3.1 presents values obtained for the measurements of Caesium-137 in the reactor and the pool water within the year 2011. The other elements were not detected. The obtained values for ^{137}Cs are lower than the minimum values stated by the Safety Analysis Report (SAR). According to the SAR, 3.4×10^5Bq/L of ^{137}Cs in the reactor and pool water respectively present minimum hazard [14] [15].

Date	Reactor Water	Pool Water
	Activity (Bq/L)	Activity (Bq/L)
28-03-2011	3.63 ± 0.51	3.74 ± 0.53
04-04-2011	3.51 ± 0.60	3.40 ± 0.48
18-04-2011	3.51 ± 0.44	2.46 ± 0.46
09-05-2011	2.48 ± 0.44	5.97 ± 0.67
16-05-2011	3.93 ± 0.53	3.86 ± 0.64

30-05-2011	4.41 ± 0.60	1.08 ± 0.32
06-06-2011	3.19 ± 0.67	2.85 ± 0.46
10-10-2011	2.04 ± 0.39	2.71 ± 0.46
21-11-2011	1.86 ± 0.39	3.58 ± 0.46
19-12-2011	2.25 ± 0.37	2.32 ± 0.30

Table 3.1: Reactor and Pool Water values of Caesium-137

If water quality is not good enough, it will result in curd deposits on fuel cladding which will affect the heat conduction properties of the fuel elements. Poor water quality will also increase pit corrosion. The reactor and pool water purification is therefore carried out on Mondays and the water quality is monitored. The monthly average resistivity values measured are converted to conductivity using eq. 3.1

$$C = 1/\rho \ (\mu S) \qquad 3.1$$

Where C = Conductance in cm/Ω or (μS)

ρ = Resistivity in Ω/cm or (MΩ/cm)

The permissible conductivity ranges for both reactor and pool water are 0.5 – 1.0 μS and 1.0 – 2.0 μS according to the SAR. Table 3.2 shows some measurements.

Due to pump breakdown, measurement for the pool water was not done in December 2011.

Month	Average Reactor Water Quality (MΩ/Cm)	Conductivity of Reactor Water (μS)	Average Water Quality (MΩ/Cm)	Conductivity of Pool Water (μS)
January	1.975	0.5	0.675	1.5
February	1.200	0.8	0.720	1.4
March	1.225	0.8	0.750	1.3
April	1.913	0.5	0.733	1.4
May	1.912	0.5	0.940	1.1
June	1.938	0.5	1.068	0.9
July	1.913	0.5	1.240	0.8
August	2.000	0.5	1.196	0.8
September	1.788	0.6	1.500	0.7
October	1.643	0.6	0.950	1.1
November	1.853	0.5	1.117	0.9

December	1.867	0.5	-	-

Table 3.2: Reactor and Pool Water Conductivity

4.0 MODIFICATION OF EXISTING COMPONENTS

4.1 Micro Computer Closed Loop System

In GHARR-1, two independent control systems are used to operate the reactor; control console (CC) and micro-computer closed loop system (MCCLS). Several parts and components have been replaced, as a result of ageing and obsolescence. The micro-computer control system was finally replaced with a new one in 2008 with the operating system changed from Disk Operating System (DOS) to Windows “eXPerience” (Win XP). The interface board sockets have been changed from Industrial Standard Architecture (ISA) to Peripheral Component Interconnect (PCI) making the system user friendly. The new system has been improved based on the original system. Some circuits have been adjusted and some monitoring parameters added to make the new system perfect. The new version provides the neutron flux, inlet and outlet temperatures, control rod position, reactor water and pool water conductivity, pool water temperature, preset options, data analysis tools and a lot more features that allows for an interactive use of the system. After shutdown, the operating data are stored in EXCEL SHEET. Figure 4.1 shows the hardware of the computer control system.

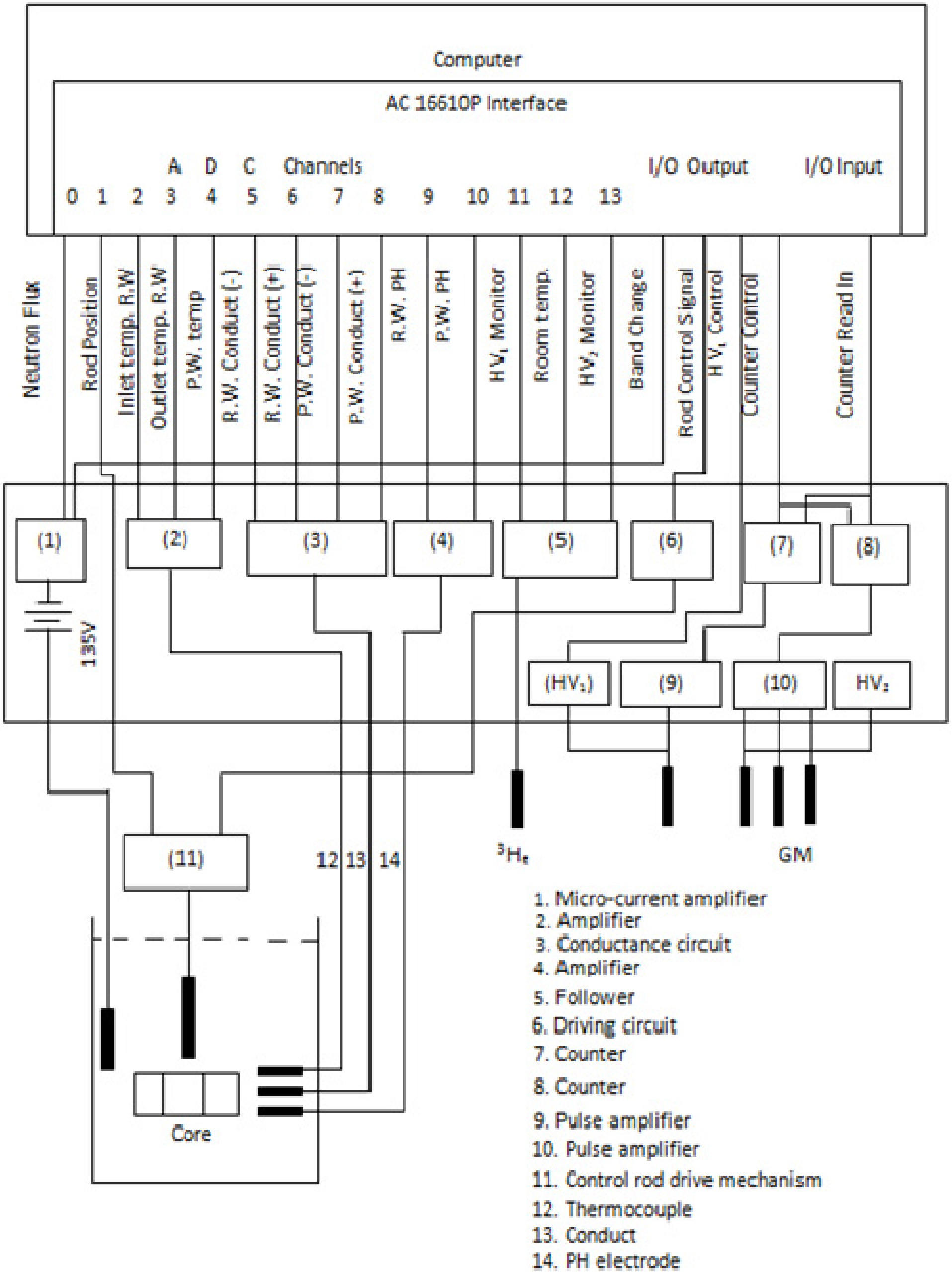

Figure 4.1 Hardware of the computer control system

The cost of the project was borne by the IAEA under REP No. GHA 4012-001-001N/IAEA. Three experts from China Institute of Atomic Energy (CIAE) were in Ghana for the project.

4.2 Control Rod Drive Mechanism

The control rod drive mechanism was replaced with a newer version in August 2009. The installation was performed by the staff of GHARR-1. Following procedures approved by the regulatory authority.

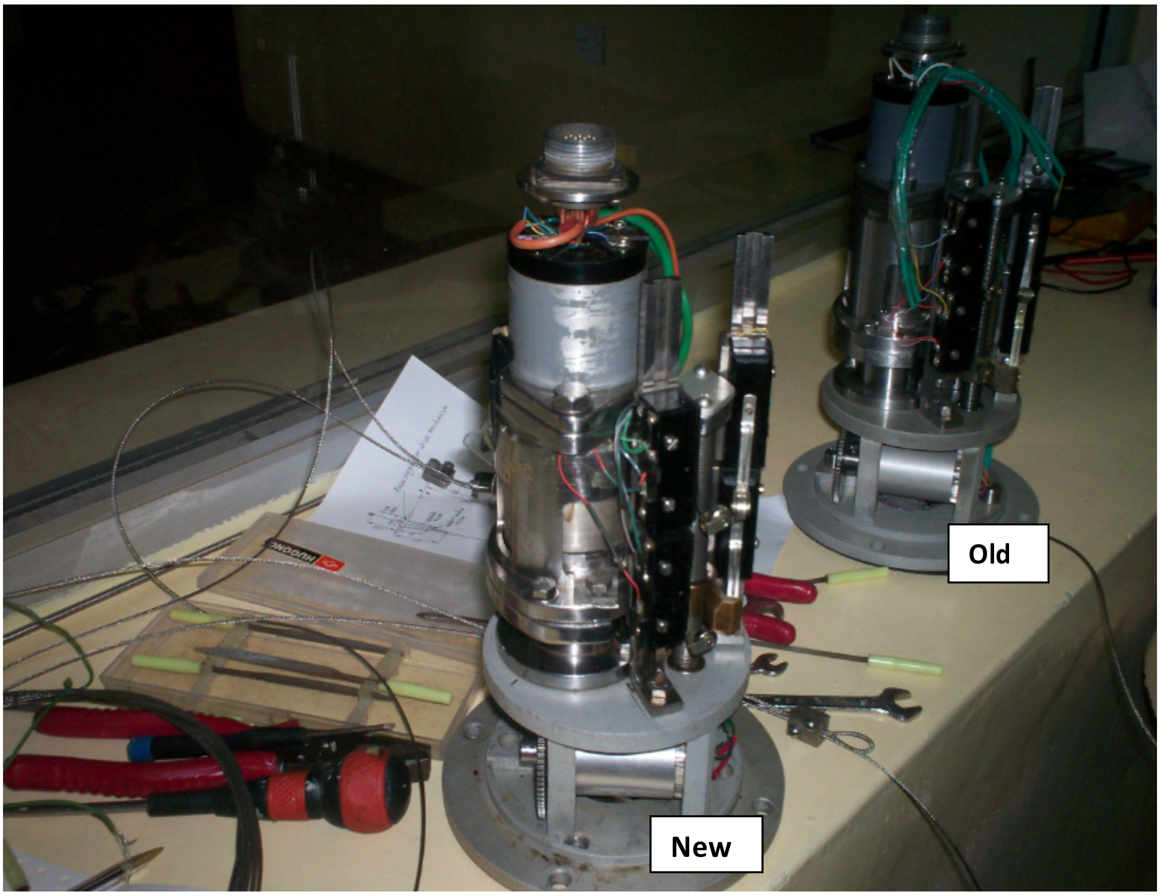

Figure 4.2. Old and New Control Rod Drive Mechanism

Figure 4.3. Installation by local team

4.2.1 Activities Carried Out

A. Measurement Procedure

Measurements were made for the new control rod drive mechanism between;

1. The drive wheel and first clamping block
2. The drive wheel and second clamping block
3. The second clamping block and the plumb of the control rod

It was realized that some maintenance work carried out on the old control rod drive mechanism had altered the length of the wire rope but it still did function normally.

B. Replacement Procedure

1. Radiation monitoring was conducted to ensure health safety of personnel.
2. The old control rod drive mechanism was disengaged and the control rod removed and allowed to dissipate off its radioactivity in the pool for three days.
3. The whole setup of the new control rod was then placed in the reactor core after all required measurements had been adhered to and the drive mechanism had been configured. The drive mechanism was then tested by fixing it on the reactor.

4. On switching the console, the rod position indicator on the console moved to 140 mm instead of zero. The console was switched off and the two autosyns (the transmitter and the receiver) were synchronized by readjustment of the dial on the receiver).

5. The console was switched on again and the dial remained at the zero position.

6. The flux build up was then tested for at a preset value of 1×10^9n/cm^2 s. The rod lifted to 230mm to allow for the flux build-up. On removing the first cadmium capsule, there was no significant flux build-up. This remained so until the fourth capsule was removed.

7. After the removal of the cadmium capsules and string from the inner site of the reactor, the flux build-up was found to be extremely slow. Also, after the completion of the flux build-up process, the control rod position indicator showed that the control rod position did not drop but remained at a high value.

8. It was concluded that the length of the rope wire was too long to allow the normal operation of the control rod drive mechanism. The reactor was shut down again and the cadmium string and capsules were sent back into the reactor. To determine how much wire rope was to be removed, the base of the control rod drive mechanism was packed with 15 mm thick wood while ensuring that the rod was still in its guide and the reactor was operated. There was a noticeable change in the rate of flux build-up although it was still too slow. The procedure was repeated with 25mm, 40mm and finally 70mm thick wood. At 70mm, the rate of flux build up was found to be normal.

9. The necessary adjustments to the wire rope were made (i.e. 70mm of wire rope was removed) and the control rod drive mechanism was placed on the reactor. The reactor was operated as usual at 1×10^9n/cm^{2}s, the cadmium strings and capsules were removed and the flux build up now appear normal.

10. The reactor was shut down and operated again the next day to ensure that its operation remained normal.

11. The installation of the new control drive mechanism started on 4th August, 2009 and completed on the 19th August, 2009.

12. The new dimension set-up of the new control rod drive mechanism was shown in fig 4.2.

Challenges:

- It was obvious that the design of the new control rod drive mechanism was different from the old one. Hence new measurements had to be taken and adjustments made where necessary.

  In doing this, the original design measurements of the old drive mechanism was used to configure the new one since it did not have any accompanying document to assist in its installation.

- After the detection of the slow build-up of flux, measurements were then taken for the mass and length of the plumbs of both the new and the old control rod. It was realized after taking the measurements that, both the length and mass of the plumb of the new control rod assembly, fell short significantly of the old control rod assembly. The length of the new plumb was 180mm while that of the old was 218mm. Of much interest was the mass of the new rod which fell short of the 1kg standard used in most literature concerning the reactor. Whereas the plumb of the old control rod had an average mass of 824.48g, the plumb of the new control rod had an average mass of 640.30g. So we were compelled to use the old plumb to ensure prompt scram of the reactor.

- As a result, the end of the wire rope of the new control rod drive mechanism was knotted in such a way that it could be accommodated by the old control rod assembly.

All procedures carried out were done with careful adherence to all safety measures put in place for the particular type of exercise. The new control rod drive mechanism, has thus, been successfully installed while maintaining the old control rod in the reactor setup. The measurements taken before and after installation are captured in table 4.1 below.

Before the Installation				
Rise Time	Falling Time	Criticality $1x10^9 n/cm^2 s$	Half Power(15kw) $5x10^{11} n/cm^2 s$	Build-up Time
28 Sec	**28 sec**	**125 mm**	**154 mm**	**3 mins 20 Secs**
After the Installation				
Rise Time	Falling Time	Criticality $1x10^9 n/cm^2 s$	Half Power (15kw) $5x10^{11} n/cm^2 s$	Build-Up Time
26 Sec	**26 Sec**	**130 mm**	**154 mm**	**2 mins**

Table 4.1 Measurements before and after installation

4.3 CONSTRUCTION OF SLANT TUBE

The existing irradiation sites accommodate only small samples. The guide (slant) tube enables larger samples to be irradiated and also carry out some experiments owing to its volume efficiency. The existing two (2) slant tubes developed some holes and were removed.

The guide tube was constructed using aluminium sheet and moulded into a cylindrical tube and joined together by an electrical welding as shown in fig. 4.4 below.

The tube is 15 cm in diameter and total length of 540 cm. A plunger of aluminum material was designed and moulded to be plugged into the tube. The dimension of the plunger is 150 cm by 18 cm as shown in fig.4.5 with a special cover 9 cm by 31cm fig. 4.6. Lead was melted and put in the lower part of the plunger at 20 cm from the bottom likewise the cover also at 3 cm from the top. The lead was used to prevent the possibility of radiation escaping into the reactor hall during operation.

Fig 4.7 shows the installation of the guide tube on the reactor vessel. The tube was fixed 20 cm from the reactor vessel on a stainless steel plate of the following dimensions: thickness was 1.5 cm, length 105 cm and the width 33 cm bolted onto the two I-beams stretched over the pool. The tube was fixed closed to the lower vessel of where the reactor core is seated at a distance of 5.0 cm.

4.3.1 Experimental Procedure for Guide Tube Installation

The reactor was operated under automatic mode at the neutron flux of $1x10^9$ n/cm^{2}s to obtain the core excess reactivity. The inlet and the outlet temperatures were recorded at this flux value. Gamma radiation on top of the reactor was also recoded before the installation as shown in tables 4.2.

Date	preset Neutron Flux	Measured Neutron Flux	Inlet Temp ^{0}C	Outlet Temp ^{0}C	Gamma Dose µG/hr	Ctrl Rod Position mm
01/11/10	$1x10^9$n/cm^{2}s	$1x10^9$n/cm^{2}s	33.1	33.2	0	140

Table 4.2 Parameters recorded at $1x10^9$ n/cm^{2}s before the installation

Four cadmium rabbits and a string were pumped into the inner irradiation sites to ensure subcriticality of the reactor.

The slab holding the old guide tube was removed and a new one fixed. The guide tube was lowered with the help of a 5 tones crane fixed in the reactor hall through 18 cm hole in the slab and bolted it firm in position.

The cadmium rabbits and the string were pumped out and operated the reactor at the same neutron flux to ensure the stability of the reactor.

It could be seen from the data shown in table 4.4 that after 18 min of reactor operation when the slant tube was installed without the insertion of the plunger, there was increase in gamma dose at the top of the reactor vessel. The gamma dose reduced after the plunger insertion fig. 4.5. This could be attributed to the interaction of air molecules with charge particles in the slant leading to the emission of radiation.

4.3.2 Financial Support

Financial support for the project was provided by the International Atomic Energy Agency (IAEA) through the CRP GHA15171

Date	preset Neutron Flux	Measured Neutron Flux	Inlet Temp ^0C	Outlet Temp ^0C	Gamma Dose µG/hr	Ctrl Rod Position mm
01/11/10	$1x10^9 n/cm^2s$	$1x10^9 n/cm^2s$	34.7	34.7	0	138

Table 4.3- Parameters recorded at $1x10^9$ n/cm^2s after the installation

Time	Date	preset Neutron Flux (n/cm^2s)	Measured Neutron Flux (n/cm^2s)	Inlet Temp ^0C	Outlet Temp ^0C	Gamma Dose (µG/hr)	Reactor Power (KW)	Ctrl Position (mm)
11:00	9/11/10	$5.0x10^{11}$	$5.67x10^7$	35.2	35.2	0	15	0
11:18	9/11/10	$5.0x10^{11}$	$5.01x10^{11}$	38.5	48.5	> 91	15	162

Table 4.4 Recordings at 5 x 10^{11} n/cm^2s before the insertion of the plunger

Time	Date	preset Neutron Flux (n/cm^2s)	Measured Neutron Flux (n/cm^2s)	Inlet Temp °C	Outlet Temp °C	Gamma Dose on top of Reactor (μG/hr)	Ctrl Rod Position (mm)
10:48	10/03/11	$1.0x10^9$	$8.0x10^7$	36.5	36.5	0	0
10:55	10/03/11	$1.0x10^9$	$1.0x10^9$	36.4	36.4	0	120
11:00	10/03/11	$5x10^{11}$	$4.99x10^{11}$	37.5	47.6	56	146
11:30	10/03/11	$5x10^{11}$	$5.00x10^{11}$	40.3	50.1	52	144

Table 4.5 - Recordings after inserting the plunger and operated at $5x10^{11}$ n/cm^2s

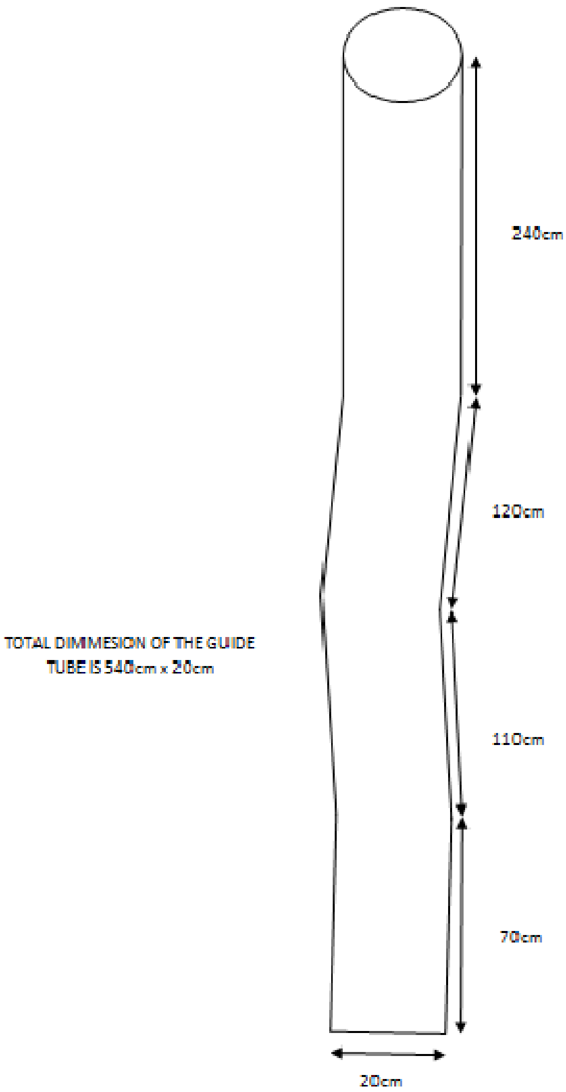

Fig.4.4. Slant tube

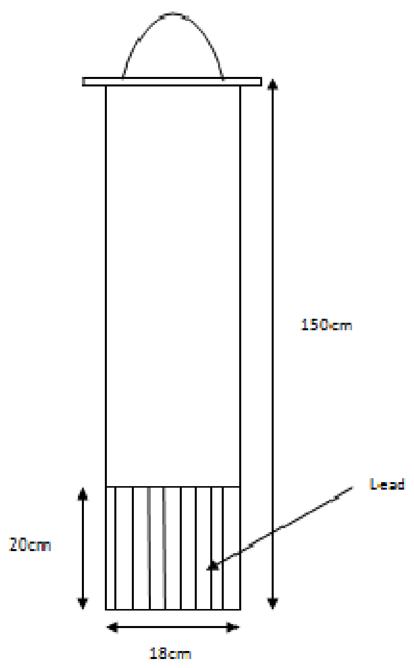

Fig. 4.5. Plunger

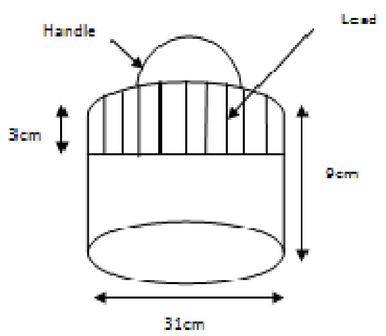

Fig. 4.6. Slant tube cover

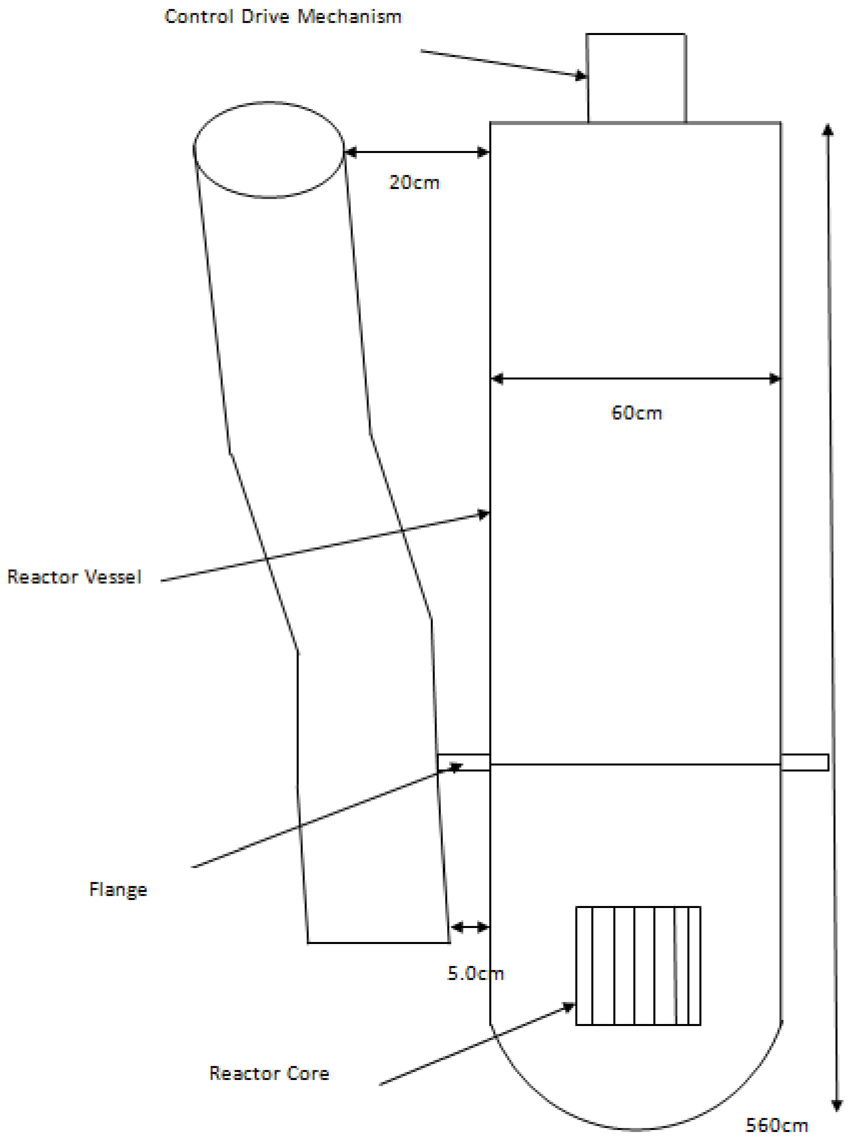

Figure 4.7. Vertical cross section of the reactor showing the slant tube

4.4 Refurbishment of deionized water plant

The facility is designed for production of pure water (light water) to top up the reactor and the pool water respectively. The main design parameters to be satisfied for providing quality pure water for the miniature reactor are:

Water flow rate: 0.5 – 0.7 m^3/h

Conductivity ≤ 1μS/cm

pH = 6.0 ± 0.5

The content of ions such as Fe^{+3}, Cu^{+2}, Cl^- are less than 0.1 mg /L respectively.

Fig. 4.8 below shows the flow chart for processing of the light water for the miniature reactor.

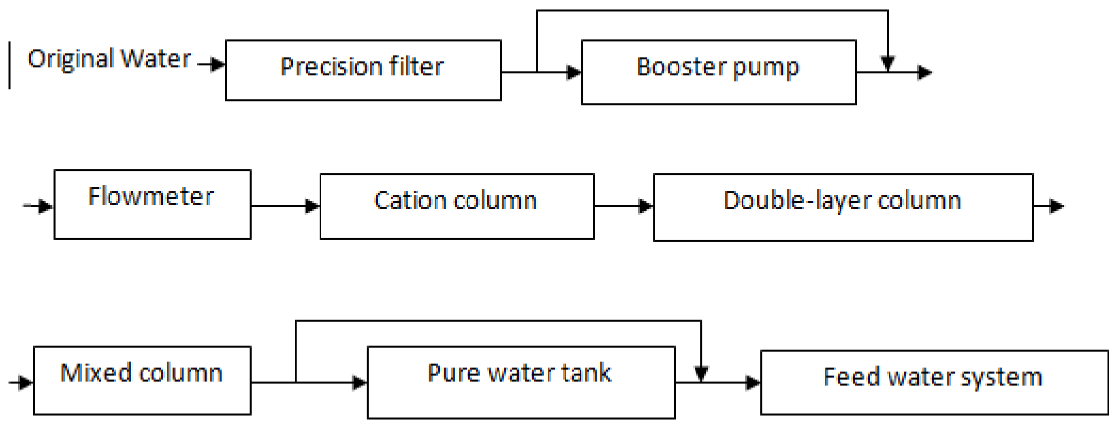

Fig.4.8. Flow chart of pure water processing

The resins in the plant columns were replaced in December 2012. The pipes and the valves were also replaced in November 2012 as a result of brittleness due to ageing. The resins have been regenerated twice, 2005 and 2010. Fig. 4.9 shows the purification system.

Fig.4.9. New deionized plant

Fig. 4.10: Reactor water purification system

Fig.4.11: Reactor pool water purification system

5.0 DESIGN FEATURES FOR COMPONENT REPLACEMENT

A crane rail runs the large access door over the reactor pool to the roof wall of the reactor hall. The rail carries a crane of lifting capacity of 5 tons and height 135 cm from the bottom of the pool. The maximum clearance between the top of the reactor pool and the bottom of the crane hook is 55 cm. The reactor vessel is in two sections, the upper and the lower section. The two-section design of the reactor vessel facilitates the installation of the reactor core and the core replacement after its useful life without any loss of shielding using the crane.
A long handling tool is provided to remove the core and placed in the pool. The same tool is used to lift the aluminium tray on top of the reactor core for beryllium addition.
Four (4) cadmium capsules of 4 mk worth is provided for shutting down the reactor in the event of a failure of the control system. This system is not automatically actuated at the onset of an abnormal condition. Auxiliary shutdown is accomplished by the manual insertion of cadmium capsules into the inner irradiation sites. To ensure deep subcritical reactivity of the reactor, additional string of cadmium capsules at the same worth is available to replace the control rod when failure occurs.

6.0 PERIODIC SAFETY REVIEW FOR GHARR-1

Safety reviews are performed regularly to ensure adherence to regulations governing reactor systems operation. The Reactor Safety Committee (RSC) as well as the Radiation Safety Committee (RadSC) perform regular safety reviews and make recommendations to the Reactor Manager and the Director of NNRI for the necessary actions to be taken.
The RSC has the responsibility to review: experiments, modification, procedures, reportable occurrences and personnel qualification. Review of safety documents are conducted every two (2) years prior to the safety analysis report (SAR) which is reviewed every five (5) years.

Feedback from previous safety review mission and operational experience, expert missions' recommendation and documents developed by the reactor manager and team assist in the review for onward submission to the regulatory agency for approval.
Modifications and experiments having significance effect on safety are reviewed by the reactor safety committee and recommendations made to the reactor manager for review before submission to the regulatory body for further review and approval.

7.0 AGEING OF STAFF / SUCCESSION PLAN

In accordance with Article 3 of Act (2000) which mandates the Commission to collaborate with the Universities in training and teaching in the field of nuclear energy, Ghana Atomic Energy commission (GAEC) with the University of Ghana and IAEA has established a Postgraduate School of Nuclear and Allied Sciences (SNAS) to train personnel for Ghana's nuclear practice and the Africa Region. The objectives are to preserve and enhance knowledge in nuclear technology and to develop human and institutional capacity in the field of nuclear and allied sciences. The following M.Phil. and Ph.D Courses are offered: Nuclear Engineering, Applied Nuclear Physics, Nuclear and Environmental Protection, Radiation Protection, Nuclear Agriculture, Medical Physics, Nuclear and Radiochemistry among others. Sustainable Human Resource Development (HRD) is assured.

8.0 CONCLUSION

In the eighteen (18) years of operating the GHARR-1, maintenance and safety practices have helped to reduce the effect of ageing on the operation of the reactor. Preventive and corrective maintenance of Safety Systems and Components (SSCs) is done according to written procedures, which have been reviewed and recommended by the RSC. The successful operation of GHARR-1 facility has largely depended on the management structure, safety and operational documents which are mostly based on the IAEA standards and experts' recommendations. Special precautions are taken such that materials that may have enhanced corrosive properties such as (e.g. mercury, rhenium, and magnesium) are not irradiated.

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