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Management System Activities of the Operation and Utilization of GHARR-1

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Abstract

The Ghana Research Reactor-1 (GHARR-1) is a 34 kW low enriched uranium (LEU) Miniature Neutron Source Reactor (MNSR), tank-in-pool type and cooled by natural circulation under atmospheric pressure operating conditions. GHARR-1 is owned by Ghana Atomic Energy Commission (GAEC) and operated by National Nuclear Research Institute (NNRI), one of the institutes of GAEC. GHARR-1 is housed by Nuclear Reactors Research Centre (NRRC), one of the Centres of NNRI. Management/Administration, Radiation protection, Reactor operation and maintenance, Reactor utilization and Physical protection are the various systems/units that integrate to manage the activities of operation and utilization of GHARR-1 in addition to the quality assurance and quality control management system of the research reactor facility. The GHARR-1 which is currently in operation follows a robust maintenance culture adopted by the management system and this has made it possible to keep the reactor in operation with minimal interruption. The management system activities adopted at the Centre to ensure safety of the workers, public and the research reactor facility include authorization of the operation of the reactor for any experiments/modifications; providing material and financial resources for maintaining the research reactor facility; following standard procedures while carrying out Neutron Activation Analysis; participation in IAEA proficiency test; irradiation sites/positions characterization; following standard procedures while carrying out reactor operation and maintenance including reactor and pool water purification and other related activities; monitoring radiation levels in the controlled, supervised and uncontrolled areas of the research reactor facility as well as during reactor operation and maintenance; controlling the physical entry of the workers and public into the research reactor facility; and ensuring that the security structures provided to protect the reactor facility are functioning properly. The thorough knowledge on the functions of the various components that make up the electrical/electronic and control systems of the reactor has been observed to be important for continuous successful maintenance of the research reactor to keep the reactor in operation. This work provides some management system activities adopted to monitor the activities of the research reactor operation and utilization to guarantee safety of workers, public and the environment as well as to safeguard a continuous operation of the research reactor. These management system activities adopted among others, are in the form of Monitoring Forms provided for monitoring the activities of the research reactor operation and utilization in order to ensure standard procedures and specifications are followed and quality services are rendered to the public.

Keywords

Management Systems, Quality Assurance and Quality Control, Research Reactor Operation and Utilization, Monitoring Forms, Ghana Research Reactor-1 (GHARR-1)

1. Introduction

The Ghana Research Reactor-1 (GHARR-1) is a 34 kW low enriched uranium (LEU) Miniature Neutron Source Reactor (MNSR), tank-in-pool type and cooled by natural circulation under atmospheric pressure operating conditions. The GHARR-1 facility is mainly used for Research and Development (R & D) in nuclear technique and nuclear engineering, Neutron Activation Analysis (NAA), human resource development for Ghana's nuclear power programme and for education and training [1] [2] [3]. The GHARR-1 was previously operated with a 30 kW highly-enriched uranium (HEU) core but was changed to LEU core in 2017. **Table 1** shows comparison of technical specifications of Ghana Miniature Neutron Source Reactor (MNSR) LEU core with that of the HEU core. **Figure 1** shows schematic diagram of the coolant flow pattern while **Figure 2** shows the arrangement of 335 fuel rods together with 15 dummy rods of 350 lattice structure of the LEU core [1] [2] [3]. The organizational and management structure of GHARR-1 facility is shown in **Figure 3**. As depicted by the organogram (**Figure 3**), the management/administration of the reactor facility consists of Director General of Ghana Atomic Energy Commission (GAEC), the Director of National Nuclear Research Institute (NNRI) and the Manager of Nuclear Reactors Research Centre (NRRC). The Management Board of the NNRI and that of GAEC support the Management/Administration of the reactor facility. The various units that work with the Management/Administration to run the reactor facility ensuring its operation and utilization include Reactor Operation and Maintenance Group, Reactor Utilization Group, Radiation Protection Group,

Table 1. Comparison of key parameters for reference GHARR-1 HEU and LEU cores [1] [2] [3].

Key Parameters	HEU	LEU
Reactor type	MNSR	MNSR
Fuel type	rod	rod
Power, kW	30	34
Fuel rod lattice	350	350
Number of Active Fuel rods	344	335
Number of Dummy rods	6	15
Core diameter (mm)	230	230
Core height (mm)	230	230
Fuel lattice pitch (mm)	10.95	10.95
Coolant inlet pressure (atm)	1	1
Coolant heat transfer mode	Natural convection	Natural Convection
Reflector	Beryllium	Beryllium
Control rod absorber	Cadmium	Cadmium
Control rod cladding	Stainless steel	Stainless steel
Number of control rods	1	1
Core shape	Cylindrical	Cylindrical
Coolant/moderator	Deionised water	Deionised water
Fuel Meat	$U\text{-}Al_4$	UO_2
U-235 Total Core Loading, g	~998.1	~1355.3
U-235 Enrichment, wt%	90.2	13.0
U-234 content, wt%	1.0	0.2
U-236 content, wt%	0.5	0.25
Density of Meat, g/cm^3	3.456	10.6
Meat Diameter, mm	4.3	4.3
Cladding Diameter, mm	5.5	5.5
Thickness of He Gap, mm	None	0.05
Cladding Material	Al-303-1	Zirc-4
Material for Grid Plates	LT-21	Zirc-4
Top Shim Tray	LT-21	LT-21
Material for Dummy Elements	Al-303-1	Zirc-4
Number of Tie Rods	4	4
Material for Tie Rods	Al-303-1	Zirc-4
Adjuster Guide Tubes	4	4
Effective Delayed Neutron Fraction	8.08×10^{-3}	8.57×10^{-3}
Prompt neutron lifetime(s)	8.12×10^{-5}	1.41×10^{-4}

Continued

Maximum thermal Neutron flux, n/cm^2s	1×10^{12}	1×10^{12}
Excess reactivity, mk	4.0	3.87
Control rod worth, mk	7.0	6.90
Shutdown margin, mk	3.0	3.03

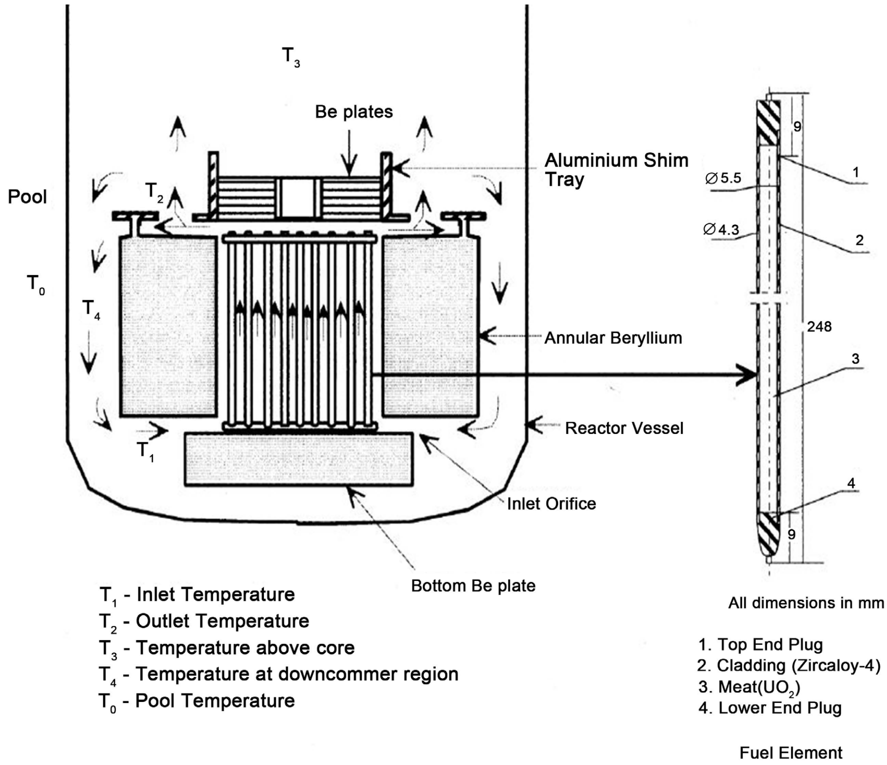

Figure 1. A schematic diagram of the coolant flow pattern in GHARR-1 [1] [2].

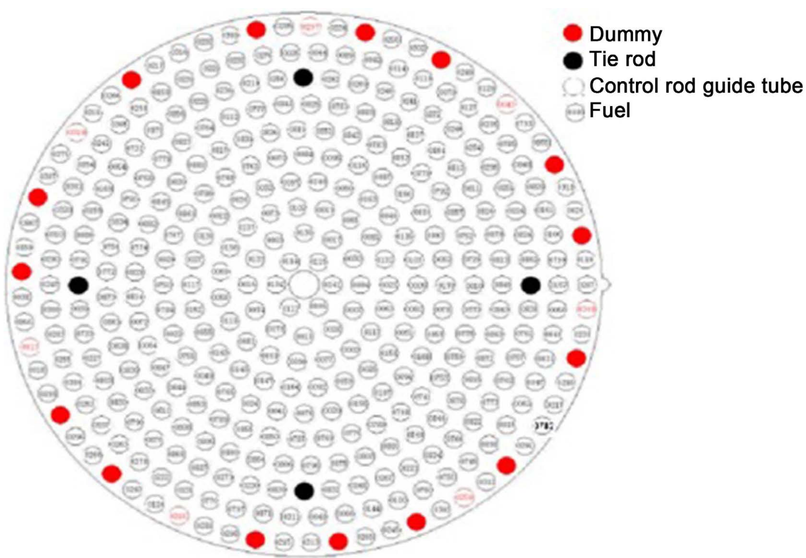

Figure 2. Fuel element arrangement of GHARR-1 core [1] [2].

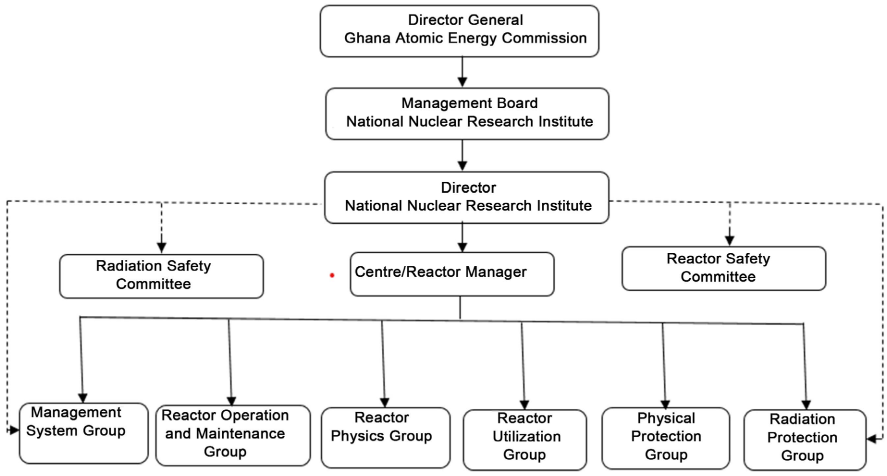

Figure 3. Organizational and Management Structure of GHARR-1 Facility.

Physical Protection Group, Reactor Physics Group, and Management System Group. A designated member of each group heads the group. The activities of the NRRC (or GHARR-1 facility) are externally regulated by the Nuclear Regulatory Authority of Ghana. The internal supervision and audit roles are performed by the Reactor Safety Committee and the Radiation Safety Committee. It is good to know that GAEC has other institutes which include Biotechnology and Nuclear Agriculture Research Institute (BNARI), Ghana Space Science & Technology Institute (GSSTI), Graduate School of Nuclear & Allied Sciences (SNAS), Nuclear Power Institute (NPI), Radiation Protection Institute (RPI), and Radiological & Medical Sciences Research Institute (RAMSRI).

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Ghana Research Reactor-1 (GHARR-1) has been operated successfully before and after its conversion from high enriched uranium (HEU) to low enriched uranium (LEU) core. The successful operation of the GHARR-1 facility over the years is due to good management system practices adopted. As mentioned earlier, the management systems adopted include also quality assurance and quality control management system as well. The management system processes and activities of the research reactor facility are guided by IAEA Safety Requirements GS-R-3, The Management System for Facilities and Activities [4], Quality Requirements ISO 9001, Quality Management Systems [5], and other related documents (Implementation of a Management System for Operating Organizations of Research Reactors, SRS No. 75 [6]; The Management System for Nuclear Installations, GS-G-3.5 [7]; Application of the Management System for Facilities and Activities, GS-G-3.1 [8]; Leadership and Management for Safety, GSR Part 2 [9]; Safety of Research Reactors, SSR-3 [10]; Licensing Process for Nuclear Installations, SSG-12 [11]; Governmental, Legal and Regulatory Framework for Safety, GSR Part 1 [12]; Safety of Research Reactors, NS-R-4 [13]; IAEA Nuclear Safety and Security Glossary Terminology Used in Nuclear Safety, Nuclear Security, Radiation Protection and Emergency Preparedness and Response [14]; Quality Assurance and Quality Control in Nuclear Facilities and Activities, IAEA-TECDOC-1910 [15]).

GHARR-1 facility is maintained by the Administration/Management who is responsible for providing material and financial resources to solve the needs of the facility. GHARR-1 facility is mainly used for Neutron Activation Analysis (NAA). The processes/activities involve in the NAA include sample preparation, sample transfer, sample counting and sample analysis. Various management system programmes are adopted to ensure NAA processes and activities are monitored and controlled by following standard procedures and specifications. This ensures that precise and accurate qualitative and quantitative elemental concentration/composition determination.

Reactor operation and maintenance, and maintenance culture adopted by the management system make it possible to keep the research reactor facility in operation for its utilization for NAA. The thorough knowledge on the functions of the various components that make up the electrical/electronic and control systems of the reactor is important for reactor operation and maintenance. The standard operating procedures and specifications are followed during reactor operation and maintenance. The reactor can be operated for less than two (2) hours at full power of 34 kW, and operated for eight (8) hours at half power of 17 kW. Various management system quality control mechanisms, which include adopting Management System Monitoring Forms and other reactor operation and maintenance checklists, are used to monitor the activities of the reactor operation and maintenance. Management system Incidence Reporting Form is also adopted to report any incidence/accident that occurs during the operation and maintenance of the research reactor. Reactor and pool water purification is one of the reactor maintenance activities that is carried out regularly. Regular monitoring of reactor and pool water helps to detect early damage or melt-down of any fuel pins that make up the reactor core.

Monitoring of radiation levels in the controlled, supervised and uncontrolled areas of the research reactor facility is crucial and important to ensure safety of the workers and the public as well. The management system programme involves determination of absorbed dose in controlled and uncontrolled areas/zones of the research reactor facility. Unexpected sharp rise in the absorbed doses observed during monitoring of radiation levels in the controlled and uncontrolled areas could give indication that there might be radiation release from the reactor core.

The management system programme also involves providing physical protection to the research reactor facility. Safeguarding the physical entry of both workers and public into the research reactor facility as well as providing physical security structures to safeguard the research reactor are the main activities of the management system physical protection programme. These physical security structures are maintained by the Management System. The performance of the physical security structures are monitored by the Management System, Nuclear Regularity Authority and International Partners such as IAEA and US Department of Homeland Security.

The GHARR-1 management system among others, ensures that 1) management system policy document/manual as well as other management system and quality assurance and quality control documents are developed; 2) implementation of all standard procedures and specifications associated with operation and utilization of the research reactor; 3) keeping records of all the management system and quality assurance and quality control documents; 4) knowledge of human resource is well managed.

The structure of this paper begins with Introduction describing GHARR-1 using a schematic diagram (**Figure 1**) and a table (**Table 1**). The Introduction provides some reference documents used to guide the implementation of the management systems in research reactor facilities, and also makes mention of some tasks that need to be carried out in the implementation of the management systems of the GHARR-1 facility. The Introduction is followed by brief descriptions on monitoring activities of research reactor utilization, reactor operation and maintenance, radiation protection and physical protection. The Management System Group and the importance of monitoring reactor operation and utilization as a management system implementation activity have been described briefly. The concluding points of the paper have been provided in the Conclusion section.

2. Reactor Utilization

GHARR-1 facility is mainly used for Neutron Activation Analysis. There are 5 major activities involve in NAA which include sample preparation, sample transfer, sample irradiation, sample counting and sample analysis. These activities are carried out following quality assurance and quality control (QA/QC) standard procedures and specifications in order to ensure safety and render quality services to the public. Information are needed from the sample preparation, sample transfer, sample irradiation and sample counting to carrying out sample analysis using k0_IAEA software. In order to ensure safety and also to ensure the right information are obtained for the sample analysis, QA/QC monitoring forms are developed for each activity of the NAA process. These QA/QC monitoring forms are shown in forms 1 to 4. The necessary information needed from sample preparation, sample transfer and sample counting/measurement are respectively shown in QA/QC monitoring Forms 1 to 3. The necessary information also needed for sample analysis and results verification (QA/QC verification by comparing results of irradiated CRMs and CRMs already implemented in the k0_IAEA software) are provided in Form 4.

Form 1. Sample Preparation

Our ref: **QAQC/NRRC/SP ……..…………** Sample No(s) or ID(s) ……..…

Quality Assurance and Quality Control (QA/QC) Checks for Sample Preparation (SP)

Sample date, sample IDs and sample masses well recorded in the sample preparation book (Select Yes or No) ……………………………………………

At least 2 certified reference materials (CRMs) and a gold standard (wire or foil) were also prepared, IDs and masses well recorded in the sample preparation book for each set of samples prepared for Short, Medium or Long periods of irradiation (Select Yes or No) ……………………

Samples well packaged and sealed using packaging materials and soldering iron to prevent/minimize sample breakages during sample transfer and irradiation (Select Yes or No) ……………………

Select the form of sample prepared (powder, liquid, wire, foil, slab) that was prepared …………………

Remarks/Observations: ………………………………

QA/QC Officer ………………………… Name: ……………… Signature:

NAA-Sample Preparation ………………Name: ……………… Signature:

Team Member

Centre Manager ………………………… Name: ……………… Signature:

Date: ………………………..

Form 2. Sample Transfer

Our ref: **QAQC/NRRC/ST/INT/…..……** Sample No(s) or ID(s) …………

Quality Assurance and Quality Control (QA/QC) Checks for Sample Transfer (ST)

Sample transfer procedures read prior to the start of Sample Transfer In and Out of the reactor (Select: Yes or No) …………………………

Neutron Flux stable at …………………….. $n \cdot cm^{-2} \cdot s^{-1}$

Radiation Monitor and Watch (Timer) available for monitoring radiation dose and recording irradiation time (Select: Yes or No) ……………….

Sample receiving container well stuffed with foam rubber material to prevent/minimize rabbit capsule breakage (Select: Yes or No) …………………..

Sample transfer irradiation site used: Inner site ……… or Outer site ………. (Indicate it)

Minimum and maximum radiation dose of irradiated samples:

……………….………… and …………………..…..… μSv/hr (Short Sample)

……………………..…… and …………..……..…… μSv/hr (Medium Sample)

……………………….…… and …………………..…… μSv/hr (Long Sample)

Number of rabbit capsules broken during irradiation …………………………

Number of irradiated samples retrieved from broken rabbit capsules …………

Number of irradiated samples that were not retrieved from broken rabbit capsules …………...

Sample transfer and sample irradiation information well recorded in the sample transfer log-book; sample ID, sample description, time in and out, irrad. Site and dose (Select: Yes or No) ………..

Is the irradiation time for the CRM(s) the same for that of the samples? (Select Yes or No) ……..

The irradiation time used for the Au flux monitor is ………………………

The irradiation Timer and Counting System Time synchronized (Select Yes or No) …………..

Purpose of Sample Transfer: ………………………………………..…………

Remarks/Observations: ………………………………………………….………….

Form 3. Sample Counting/Measurement

Our ref: **QAQC/NRRC/SP and SC/INT/…….** Sample No(s) or ID(s) …..…..

Quality Assurance and Quality Control (QA/QC) Checks for Sample Counting (SC) of irradiated/activated sample

The counting software opened for counting (select Yes or No) ……………..…

Folder created for saving the spectra of the various samples to be counted (Select Yes or No) ……….….

The Counting System Computer Time and Sample Transfer Stop Watch Time synchronized, the counting/measurement time is set, high voltage is on, the detector is on and selected for the counting (Select Yes or No) ..……………………

The counting/measurement time is ……………………………… (Indicate it)

The Dead Time percentage less than 20% during counting (Select Yes or No) ………………

The average dead time is ……………………………………… (Indicate it)

Purpose of the Sample Preparation/Counting: …………………..………………

Remarks/Observations: ……………………………………………..…………….

Form 4. Sample Analysis

Our ref: **QAQC/NRRC/SA/INT/…..…………** Sample No(s) or ID(s) ………

Please complete the form for analysis results given to clients in soft-copy or hard-copy form

Quality Assurance and Quality Control (QA/QC) Checks for Sample Analysis (SA)

Folder created in the counting folder for sample analysis (Select Yes or No) …

The k0 IAEA software opened for Sample Analysis (select Yes or No) ………

Samples, Packaging, Activation and Measurement information well entered (Select Yes or No) ………

Sample analysis and QA/QC verification performed (Select Yes or No) ………

Mass of the Au monitor used for the analysis …………………………………...

Neutron flux estimated for the analysis using the Au monitor ………………

Analysis type	Radionuclides	Concentration of Standard (mg/kg) Standard Name ……………		Concentration of Standard (mg/kg) Standard Name ……………	
		Analysis value	Reported Value	Analysis value	Reported Value
Short	Mn				
	V				
Medium	La				
	Mn				
	As				
	Na				
	K				
Long	Th				
	Fe				
	Co				
	Cs				

*Standard denotes Certified Reference Material (CRM).

Purpose of the Sample Analysis: ………………………………………………..

Remarks/Observations: …………………………………………………………

3. Reactor Operation and Maintenance

Reactor operation and maintenance is continuous and critical activity in the lifetime of the research reactor facility. The research reactor is operated for the utilization activities such as NAA. The research reactor is also operated for the purpose of maintenance activities. The research reactor maintenance activities are carried out to ensure safety of the utilization and to increase the lifespan of the reactor. The thorough annual maintenance is carried out at the beginning of the year. The annual maintenance activities are detailed in the publication by Shitsi *et al.* [1]. Weekly maintenance is also carried in addition to the annual maintenance activities. The weekly maintenance activities mainly include reactor and pool water purification among others. The QA/QC monitoring forms are provided to guide and monitor the reactor operation and maintenance activities ensuring that standard procedures and specifications are followed. The QA/QC monitoring form for reactor operation is shown by Form 5 where all the necessary information are provided to remind the reactor operators the start-up and shut-down checks to start and shutdown the reactor as well as the information necessary to check whether the power setting on the Control Console (CC) approximately equals to the actual reactor power produced by the neutron flux in the reactor core. In order to document all the necessary information necessary relating to faults detection and correction/rectification, QA/QC monitoring form for reactor maintenance activities is shown by Form 6 to monitor the faults detection and correction/rectification maintenance activities.

Form 7 shows Incident Reporting Form for operation and utilization of GHARR-1 used to report any incident that occurs during the course of reactor operation and utilization for immediate and necessary actions to be taken to resolve the incident.

Form 5. Reactor Operation

Our ref: **QAQC/NRRC/RO/INT/………** Sample No(s) or ID(s): ………..

Quality Assurance and Quality Control (QA/QC) Checks for Reactor operation

Checks	Yes/No
1) Sample Transfer Pressure within 0.15 to 0.25 MPa	
2) Reactor operation check list followed prior to the start of reactor operation	
3) Flux stable at the required flux (half power, 5×10^{11} n·cm^{-2}·s^{-1} or full power, 1×10^{12} n·cm^{-2}·s^{-1})	
4) Coolant temperature rise within the range of (10˚C to 15˚C) for half power operation and (18˚C C to 25˚C) for full power operation	
5) Reactor shutdown after operation (shutdown checks followed)	

Reactor Power (kW) or Neutron Flux (n·cm^{-2}·s^{-1}) of operation: ………………

Initial Inlet coolant temperature (˚C): ………………………………………

Maximum Inlet coolant temperature (˚C): …………………………………..

Corresponding Outlet coolant temperature (˚C): …………………………

Corresponding Coolant temperature rise (˚C): ……………………………

Estimated Thermal-hydraulic Reactor Power (kW): …………………………..

Sample Transfer Pressure (MPa): ………………………………

Maximum Gamma Ray Dosimeter Value (μ·Gy/hr): ……………………….

Purpose of reactor operation: ……………………………………………………

Remarks/Observations: ………………………………………………………….

Form 6. Fault Detection and Rectification Description

Our ref: **QAQC/NRRC/RM/INT/…….. FAULT NUMBER/YEAR: …../…..**

Date of fault detection: ……………………..

Fault description	Description of actions taken to rectify/correct fault detected	Effect of fault on Reactor Operation
Brief description of fault detected:	Brief description on replacement/repair of components:	Number of days, weeks or months the reactor was out of operation:
How was the fault detected?	Brief description of any other actions taken:	Any other effect:
Electrical/electronic components and/or reactor components affected:		
Fault Ref. No.:	Time spent on replacement/repair of components (time spent on fault rectification):	

Remarks/Observations: ……………………………………………………………

Form 7. Incident Report Form for Operation and Utilization of GHARR-1

Personal information of the Person/Staff completing the incident report form	Name Title/Position Job Description Date and Signature
Names of Witnesses (if any)	
INCIDENT DESCRIPTION	
Date and time the incident occurred	Date: Time:
Location of the incident	
Component/System affected	
Safety classification of the component/system (SSCs)	Safety Class 1 Safety Class 2 Safety Class 3 Safety Class 4
Description of the incident	
Immediate actions taken to contain the incident or secure the incident area	
Can the incidence be resolved within three (3) working days?	Yes, the incident can be resolved No, the incident cannot be resolved
Actions taken to resolve the incident (or Actions to be taken to resolve the incident if the resolution is not possible within 3 working days).	

Continued

Number of day(s) taken to resolve the incident	
Can the Reactor be operated without resolving the incident?	Yes, the Reactor can be operated No, the Reactor cannot be operated
INCIDENT REPORTING (REPORT THE INCIDENT WITHIN 7 WORKING DAYS)	
Date and Time the incident reported to the Manager	
Date and Time the Manager reported the incident to the:	
Director	
Reactor Safety Committee	
GAEC Security	
Director General	
NRA	

*GAEC, Ghana Atomic Energy commission; *NRA, Nuclear Regulatory Authority of Ghana; *SSCs, Structures, Systems and Components.

4. Radiation Protection

Form 8 shows Monitoring Form for monitoring average hourly Absorbed Dose in a Month of workers of NRRC (the Centre housing GHARR-1 facility). The Form 7 data are obtained from weekly radiation monitoring data taken using a radiation Survey Meter (or Hand-Monitor). Any observed value more than 0.52 μSv/hr (1 mSv/year) and 10.42 μSv/hr (20 mSv/year) using the Survey Meter shows exposure to radiation above the recommended dose limits for public and radiation occupational workers respectively.

Form 9 (A and B) shows Monitoring Form for monitoring annual absorbed dose levels of workers of NRRC using Film Badge Dosimeters/Thermoluminescent Dosimeters (TLDs). The workers of NRRC are grouped in various sections/units of Reactor Maintenance and Operation, Reactor Utilization, Radiation Protection, Physical Protection, Management System and Administration. Currently, the Physical Protection Officer is also a member of the Reactor Maintenance and Operation group. Any worker with the observed annual absorbed dose value more than 1 mSv (for public exposure) and 20 mSv (for occupational exposure) during the year shows that the worker might have been exposed to radiation more than the recommended values during the year (see Forms 7and 8, and Table 2 stating the absorbed dose limits). Table 3 shows typical example of recorded annual absorbed dose values of NRRC workers from periods of 2018 to 2021. The recorded values show that no worker was exposed to radiation more than the recommended dose limit value of 20 mSv in a year for radiation occupational workers.

Form 8. Radiation Zones/Areas Monitoring Using Survey Meter (or Hand-Monitor)

	Average Hourly Absorbed Dose in a Month (μSv/hr)		
Month	**Controlled area**	**Supervised area**	**Uncontrolled area**
January			
February			
March			
April			
May			
June			
July			
August			
September			
October			
November			
December			
Average Values			
Total Values			

*Limits: 0.52 μSv/hr (for uncontrolled area) and 10.42 μSv/hr (for controlled and supervised areas).

Form 9A. Annual Personal Dose Monitoring Using Film Badge Dosimeter/TLD

Personnel/Workers	Annual effective dose (mSv)
Reactor Operation and Maintenance	
1.	
2.	
3.	
4.	
5.	
6.	
Reactor Utilization	
7.	
8.	
9.	
Radiation Protection	
10.	
Management System	
11.	
Administration	
12.	
13.	

Form 9B. Annual Personal Dose Monitoring Using Film Badge Dosimeter/TLD

Personnel/Workers in Groups	Annual average effective dose (mSv)	Annual total collective effective dose (mSv)
Reactor Operation and Maintenance		
Reactor Utilization		
Radiation Protection		
Management System		
Administration		

*Limits: 1 mSv/year and 20 mSv/year.

Table 2. Dose Limits Recommended by International Commission on Radiological Protection (ICRP).

Type of Dose Limit	Limit on Dose from *Occupational Exposure*	Limit on Dose from *Public Exposure*
Effective Dose	20 mSv per year, averaged over defined periods of 5 years, with no single year exceeding 50 mSv	1 mSv in a year
Equivalent Dose to the Lens of the Eye	20 mSv per year, averaged over defined periods of 5 years, with no single year exceeding 50 mSv	15 mSv in a year
Equivalent Dose to the Skin *Averaged over* 1 cm^2 *of skin regardless of the area exposed*	500 mSv in a year	50 mSv in a year

Table 3. Film badge dosimetry results of workers of NRRC.

Occupational Group	Year	Total No. of Workers	Annual total collective effective dose (mSv)	Annual average effective dose (mSv)
Reactor operation and maintenance	2018	6	1.62	0.27
	2019	8	6.64	0.83
	2020	7	6.23	0.89
	2021	7	9.17	1.31

Continued

Reactor utilization	2018	3	0.75	0.25
	2019	5	3.25	0.65
	2020	5	4.3	0.86
	2021	9	10.08	1.12
Radiation Protection/Management System	2018	2	0.48	0.24
	2019	2	1.62	0.81
	2020	2	1.48	0.74
	2021	2	2.72	1.36
Administration	2018	2	0.4	0.20
	2019	2	1.38	0.69
	2020	2	1.5	0.75
	2021	4	2.52	0.63

5. Physical Protection

Form 10 (A and B) shows Monitoring Forms for monitoring physical protection/security structures of GHARR-1 facility. Physical security structures such as Turnstile gate (door or barrier) for restraining movement and for allowing physical entering into the controlled area of the GHARR-1 facility, security doors and security cameras (closed circuit television (CCTV) system) are monitored to ensure they are functioning properly in addition to the 24/7 hours physical security surveillance provided by the GAEC security guards to safeguard and protect the research reactor facility [16]. The inspection team that monitors the performance of physical security structures includes the GAEC Administration/Management, Nuclear Regulatory Authority of Ghana and International Partners such as IAEA and Office of Radiological Security (ORS) in the United States of America.

Form 10A. Inspection of Security Structures

Checklist	Select (Yes/No)	Remarks
Is physical entry into the Reactor facility secured 24/7 hours?		
Is the Turnstile gate functioning properly?		
Is the Security doors functioning properly?		
Is the security cameras (CCTV system) functioning properly?		

*CCTV, closed-circuit television.

Form 10B. Frequency of Inspection of Security Structures (Turnstile Gate, Security Cameras, Security Doors)

Inspection Team	Frequency of Inspection (No. of Month(s)/Year(s) interval)	Remarks
Management/Administration		
NRA		
IAEA		
Office of Radiological Security (ORS)		

Inspection Team: ……………………………………………………..
Purpose of Security Inspection: ………………………………………………
Remarks/Observations: …………………………………………………….

6. Management System Group

Management System Group is one of the units/groups within Nuclear Reactors Research Centre (NRRC) of National Nuclear Research Institute (NNRI), one of the institutes of Ghana Atomic energy Commission (GAEC). The Management System Group works in conjunction with the Management/Administration to ensure the implementation of the management system programmes in the Reactor Centre, NRRC. The Management System Group is responsible for Quality Assurance and Quality Control activities and monitors the operations/activities of the Reactor Operation and Maintenance Group, Reactor Utilization Group, Radiation Protection Group and Physical Protection Group to ensure that standard requirements and specifications are met with the aim of protecting the workers and public from being exposed to radiation levels above the safety limits as well as ensuring quality services are rendered to the public. Management System Group also ensures that safety procedures are adhered to in the day-to-day activities of the Reactor Operation and Maintenance, Reactor Utilization, Radiation Protection and Physical Protection Groups. Adherence to safety procedures ensures that irradiation of various geological, biological and liquid samples for elemental analysis (using NAA) and preparation of reports on irradiated samples are carried out to meet required specifications and standards.

7. Importance of Monitoring of Reactor Operation and Utilization as a Management System Implementation Activity

This management system document outlined some important management system activities adopted to monitor the activities of the research reactor operation and utilization to guarantee safety of workers of GHARR-1 and the public as well as to safeguard a continuous operation of the research reactor.

Monitoring of management system activities relating to reactor operation and utilization is the approach adopted to ensure quality assurance and quality control procedures and specifications are implemented as well as ensuring the safety of the research reactor facility, the public and the environment. The following are other advantages of monitoring research reactor operation and utilization with regards to management system implementation:

1) Implementation of quality assurance and quality control (QA/QC) programmes at GHARR-1 is helpful in early detection of safety issues/concerns with regards to the research reactor operation and utilization.

2) Timely detection of safety issues/concerns helps to address them early to prevent occurrence of major/significant problems with regards to the reactor operation and utilization.

3) Implementation of the management system programmes could be used as a tool for risk identification and prevention, and hence ensuring safe operation and utilization of research reactor facilities. That is the implementation of the management system programmes can be used as a tool for taking corrective actions for the various risks identified.

4) The implementation of the management system programmes can be used as a tool to improve safety, technical procedures, and overall management performancein relation to reactor operation and utilization.

5) Implementation of management system programmes helps in rendering quality services to the public/customers that need services that are related to research reactor operation and utilization.

6) All the necessary documentation associated with research reactor operation and utilization is developed and well-maintained. Management System, among others, is focused on documents development, identification/location and control.

7) Nuclear knowledge management and transfer is sustained with regards to human resource development.

8) Customers/public have confidence in the services rendered by Ghana Research Reactor-1 Facility.

8. Conclusions

Management system that integrates all the activities of the research reactor operation and utilization is important to ensure that the objectives of the research reactor operation are achieved in safe manner with regards to the safety of the environment as well as the workers and the public. The management system ensures that all the activities of the research reactor operation and utilization are carried out following standard procedures and specifications. GHARR-1 has been operated over the years and it is still in operation because of its robust management system. GHARR-1 is mainly used for research & development, neutron activation analysis and for education and training. The GHARR-1 management system integrates all the activities of research reactor operation and maintenance, reactor utilization, radiation protection and physical protection ensuring that quality service is rendered to the public without any compromise of safety. Quality Assurance and Quality Control (QA/QC) monitoring forms have been developed and used to monitor these reactor operation and utilization activities. The Management System is also focused on documents development, identification/location and control.

The GHARR-1 management system among others, ensures that 1) management system policy document/manual as well as other management system and quality assurance and quality control documents are developed; 2) implementation of all standard procedures and specifications associated with operation and utilization of the research reactor; 3) keeping records of all the management system and quality assurance and quality control documents; 4) knowledge of human resource is well managed.

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Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

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