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STORAGE AND TRANSPORT OF SPENT FUEL FROM GHANA RESEARCH REACTOR-1 FOR CONVERSION FROM HIGHLY-ENRICHED URANIUM TO LOW-ENRICHED URANIUM FUEL

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ABSTRACT

Ghana Research Reactor-1 is a Miniature Neutron Source Reactor that is currently fueled with highly-enriched uranium aluminium alloy fuel. Efforts are underway to convert the core to a low-enriched uranium oxide fuel through the International Atomic Energy Agency's Coordinated Research Project on Core Conversion. The temporal storage of the spent fuel which shall be replaced with fresh low-enriched fuel in the pool of the reactor facility is discussed. The process for the transport of the spent fuel confined in a cask and the precautions that are required by regulations of the Radiation Protection Board of Ghana and the International Maritime Authority are jointly discussed to ensure adherence to the protocols instituted for such an activity. The various regimes available for such a transaction are reviewed and recommendations are made to provide a basis for selecting the possible option for the transport of the spent fuel of the facility.

INTRODUCTION

Ghana Research Reactor-1 (GHARR-1) is a Miniature Neutron Source Reactor (MNSR). 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 GHARR-1 core currently employs 90.2 % enriched uranium-aluminium alloy admixed in aluminium matrix as fuel. A cross sectional view of the GHARR-1 core is shown below in Figure 1. GHARR-1 attained criticality on December 17, 1994 and has since been in operation [2]. With fifteen years of experience in operating GHARR-1, Ghana has expressed the interest in deploying a nuclear power plant to form part of her electricity grid to allow the country to achieve her set targets of economic growth [3].

INSTITUTIONS FOR ASSURING SAFETY OF GHARR-1

The Atomic Energy Act 204 of 1964 established the Ghana Atomic Energy Commission (GAEC) [5]. The National Nuclear Research Institute (NNRI) is the Operating Organization of GHARR-1 and 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. Both the NNRI and RPB are provided Government of Ghana annual budgetary allocations for the operation and regulation of the reactor.

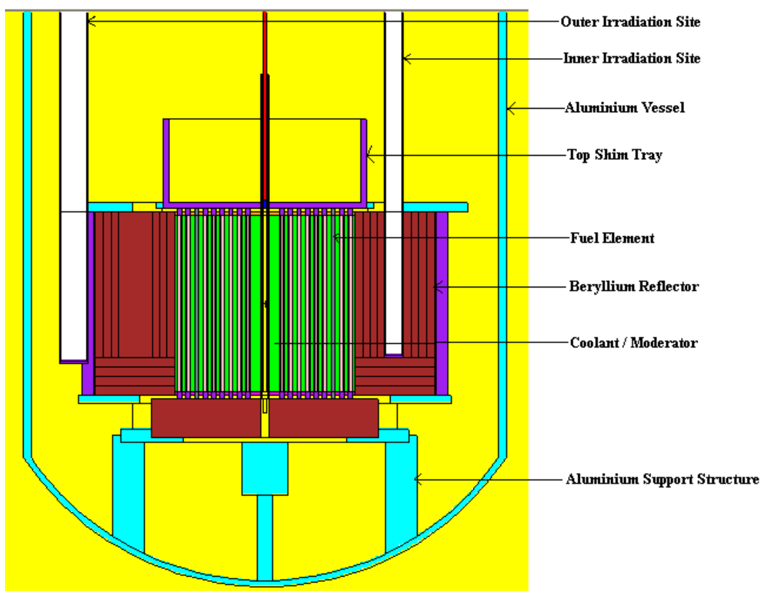

Figure 1: Vertical cross section of GHARR-1 reactor [4]

To ensure the safety of GHARR-1, the RPB performs a variety of activities, including the development and documentation of the licensing bases that specify plant design requirements and operation and maintenance (O&M) practices; the inspection and enforcement of license requirements; the performance of technical research and analysis; and the modification of regulatory requirements as needed. All of these activities are geared towards the safe operation and regulation of GHARR-1.

Although the RPB plays a central role in assuring safety of the reactor, the primary responsibility for the safe operation of GHARR-1 rests on NNRI, the licensee. NNRI is ultimately responsible for the design, operation, and maintenance of the reactor-not only to meet RPB requirements but to assure safety. To pool resources, share experiences, and coordinate efforts, NNRI collaborates with the IAEA to provide technical assistance for the safe operation of GHARR-1.

At the Operating Organization level, responsibilities that accompany the development and implementation of the Quality Assurance (QA) program are anchored on management of GHARR-1 providing means and support to achieve objectives; personnel performing work to achieve quality and evaluation of the effectiveness of management processes and work performance [6].

During the conversion of Ghana Research Reactor-1 (GHARR-1) from high-enriched (HEU) uranium-aluminium alloy fuel to low-enriched (LEU) uranium oxide fuel, two different sets of fuel assemblies shall be involved. These are the irradiated spent fuel and the fresh fuel that shall be used to replace the spent fuel. In transporting these sets of fuel assemblies several local and international activities have to be performed to ensure safe, secured and efficient activity. The fresh LEU fuel is categorized as a Type A carriage whereas the HEU spent fuel is a Type B carriage. Each type of carriage requires careful considerations to enable their proper transport and delivery. There is an agreement with China Institute of Atomic Energy (CIAE) to return the spent fuel after its useful lifetime. The provisions also require that CIAE be involved in activities that involve the core of the reactor. This study seeks to provide some recommendations on the most feasible options available for the transport of the spent fuel from GHARR-1 during the conversion from HEU to LEU. The temporal storage of the spent fuel in the reactor pool shall also be discussed.

CONVERSION ACTIVITIES OF GHARR-1

The fuel depletion of the HEU core of GHARR-1 was studied using WIMSD/4 transport lattice code to obtain the isotopic concentration of the spent fuel which is required for conversion analysis and the selection of a cask for the irradiated fuel [7, 8]. The results indicate a gradual decrease in the ^{135}Xe inventory, and saturation trend for ^{149}Sm, ^{134}Cs and ^{135}Cs inventories as the fuel is depleted to 10,000 MWd/tU.

The neutronics analysis of GHARR-1 was initiated in the year 2001 with assistance from Argonne National Laboratory (ANL) using MCNP4c [9, 10]. The preliminary multigroup neutronic criticality calculations yielded a keff=1.00449 with a corresponding cold clean excess reactivity of 4.47mk (447pcm) compared with experimental values of keff=1.00402 and excess reactivity of 4.00mk (400pcm). The Monte Carlo simulations also showed comparable results in the neutron fluxes in the HEU core and some regions of interest. The observed trends in the radial and axial flux distributions in the core, beryllium annular reflector and the water region in the top shim reflector tray were reproduced, indicating consistency of the results, accuracy of the model, precision of the MCNP transport code and the comparability of the Monte Carlo simulations. The results further illustrated the close agreement between stochastic transport theory and the experimental measurements conducted during off-site zero power cold tests.

The input deck has been fine-tuned to perform criticality safety analysis of the facility [11]. Computational codes such as REBUS-ANL, WIMS-ANL, PARET-ANL, PLTEMP-ANL and

MCNP5/MCNPX were used to model the facility and are currently being used along with SCALE6 and RELAP5 to conduct the safety analysis for the conversion from HEU to LEU. The Conversion Safety Analysis for GHARR-1 was drafted and is currently under preparation for regulatory approval needed for the conversion.

Shipping the spent fuel will entail inter alia: Planning with shipper and consignee; Securing the right packaging, checking/obtaining its approval and validations, checking maintenance status and ancillary equipment; Finding a route and carriers, checking lifting/transfer capabilities, making bookings, arranging port assistance, escorts, etc.; Obtaining all clearance, insurance, customs etc. for planned dates; Notifying all official bodies in due time and Managing all disturbances.

TEMPORAL STORAGE OF SPENT HEU FUEL

Wet storage is the most popular storage technology for storing research reactor spent fuel. However, successful storage of aluminium-clad fuel depends on very strict water quality control. Although aluminium clad research reactor fuel has been successfully stored in water for over 40 years without significant signs of corrosion, penetration of the fuel cladding by pitting corrosion has occurred in as little as 45 days in cases where water quality has been allowed to deteriorate. Aluminium racks, tanks and pool liners used in storing aluminium clad fuel are equally vulnerable to corrosion and thus limit the life time of spent fuel storage facilities.

Fuel discharged, which shall be highly radioactive, shall be store under water to provide both cooling and shielding, at the reactor site [12]. After a period of temporary storage, the spent fuel shall be shipped to the supplier (CIAE) as per the agreement existing between Ghana and China.

The current license of the facility requires that only one set of 350 reactor fuel pins is allowed at the reactor site at any given time. This requirement shall have to be amended to allow for removal of the irradiated core and refueling with fresh LEU fuel.

The design of the MNSR allowed a large pool which shall be used for temporal storage of the storage cask as was applied for the SLOWPOKE at Montreal.

As discussed by Kennedy [13] and Hagberg and Tregunno [14], the spent fuel shall be placed in a cask and stored in the reactor pool awaiting its transport from the reactor facility.

TRANSPORT OF SPENT HEU FUEL

In addition to the radioactive and fissile properties, any other properties of the contents of the package, such as explosiveness, flammability, pyrophoricity, chemical toxicity and corrosiveness, shall be taken into account in the packing, labelling, marking, placarding, storage and transport in order to be in compliance with the relevant transport regulations for dangerous goods of each of the countries through or into which the materials will be transported, and with the regulations of the cognizant transport organizations, as well as these IAEA and RPB Regulations.

The non-fixed contamination on the external surfaces of any package shall be kept as low as practicable and, under routine conditions of transport, shall not exceed 4 Bq/cm^2 for beta and gamma emitter and low toxicity alpha emitters, and 0.4 Bq/cm^2 for all other alpha emitters. These limits shall be applicable when averaged over any area of 300 cm^2 of any part of the surface.

The radiation level at any point on the external surface of an excepted package shall not exceed 5 μSv/h.

A Transport Index (TI) shall be used to prevent radiation exposure [16]; it shall be placed on labels affixed to the package or container. The TI shall be computed using the IAEA requirements outlined in Section V of SR-TS-R-1 [14]. Figures 2 – 7 present the labels and placards that shall be used during the transport of the irradiated fuel.

A Criticality Safety Index (CSI) shall be used to prevent any unsafe accumulation of fissile packages. It shall be placed on the label affixed to the package. The CSI shall be determined as for each overpack and summed to obtain the CSI of all the packages contained [15]. The limits placed on TI and CSI shall be observed along with the maximum radiation level on the surface of the package.

A UN number of shall be selected based on the characteristic features of the irradiated fuel.

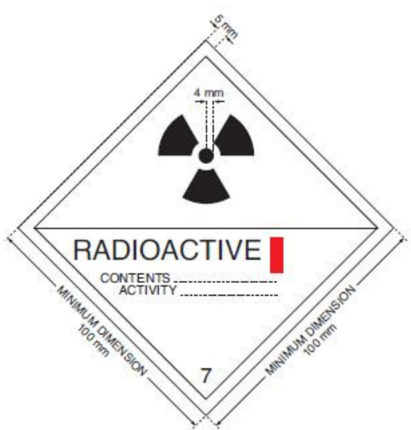

Figure 2: Category I – WHITE label [15]

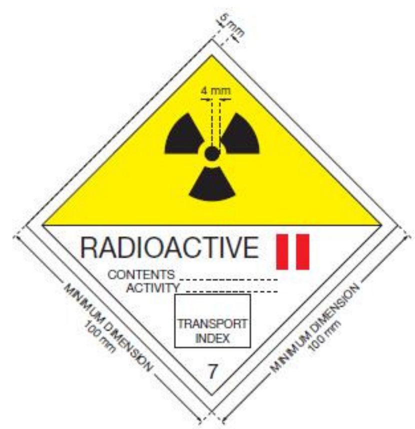

Figure 3: Category II – YELLOW label [15]

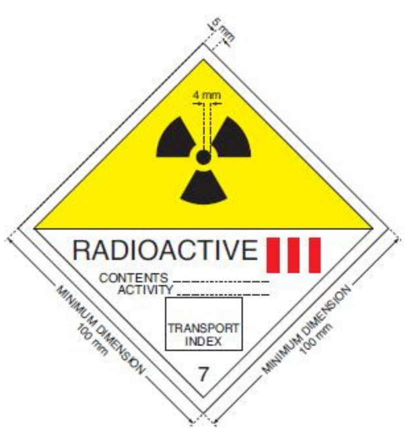

Figure 4: Category III – YELLOW label [15]

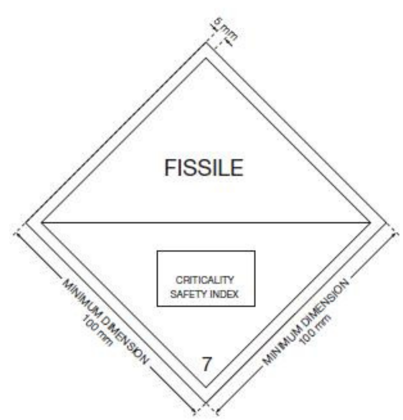

Figure 5: Criticality safety index label [15]

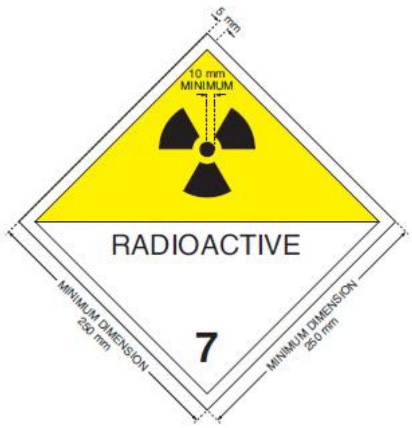

Figure 6: Placard[15]   Figure 7: Placard for separate display of United Nations number[15]

Figure 8 shows how the labels and placards shall be used during the road transport of the irradiated fuel from the GHARR-1 Centre to the Tema Port and during road transport within China.

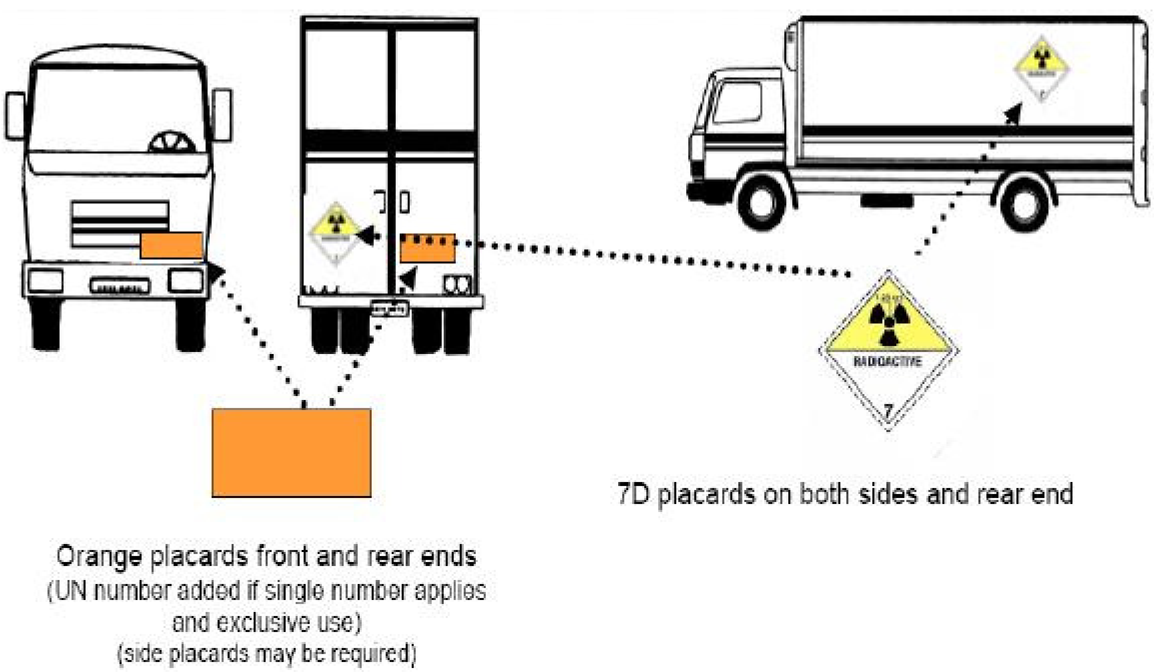

Figure 8: Placards on vehicle [16]

Testing - Normal Conditions

All types of packages (apart from excepted and some industrial packages) are required to meet performance criteria to demonstrate they will withstand normal conditions of transport, which may include minor mishaps. The package tests for normal conditions are Water Spray which simulates the effect of rain at the rate of 5 cm/hour for an hour; Stacking which simulates a compressive load equivalent to five times its own weight; Free Drop which simulates minor mishandling by being dropped from 1.2 m; and Penetration which simulates the penetration effect of a 6 kg steel bar dropped from 1 m.

Testing – Accident Conditions

For the spent fuel, the cask is designed to withstand accident conditions. The tests for accident conditions are Mechanical during which a drop of 9 m onto a surface and a drop of 1 m onto a steel punch; Thermal which involves immersion for 30 minutes in a 800 °C fire; and Water which requires immersion at 15 m underwater for 8 hours.

Functions of the Cask

The cask shall be used to remove heat, protect against impact, seal the spent core, provide gamma shielding, neutron shielding, hold the assemblies in place and help with handling and tie-down. Figure 9 presents an example of the cask which is used to transport irradiated and spent fuel.

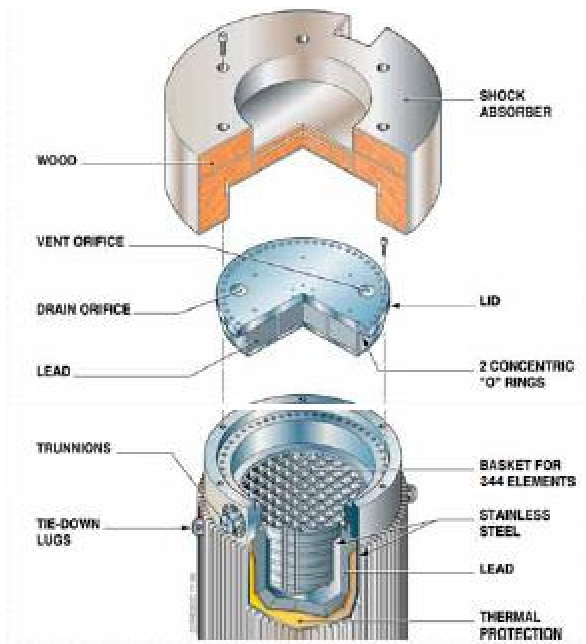

Figure 9: Cask for transporting spent fuel [16]

Figure 10 is an example of a robust vessel used in transporting Type B packages. A similar arrangement is anticipated for the transport of the irradiated fuel from GHARR-1.

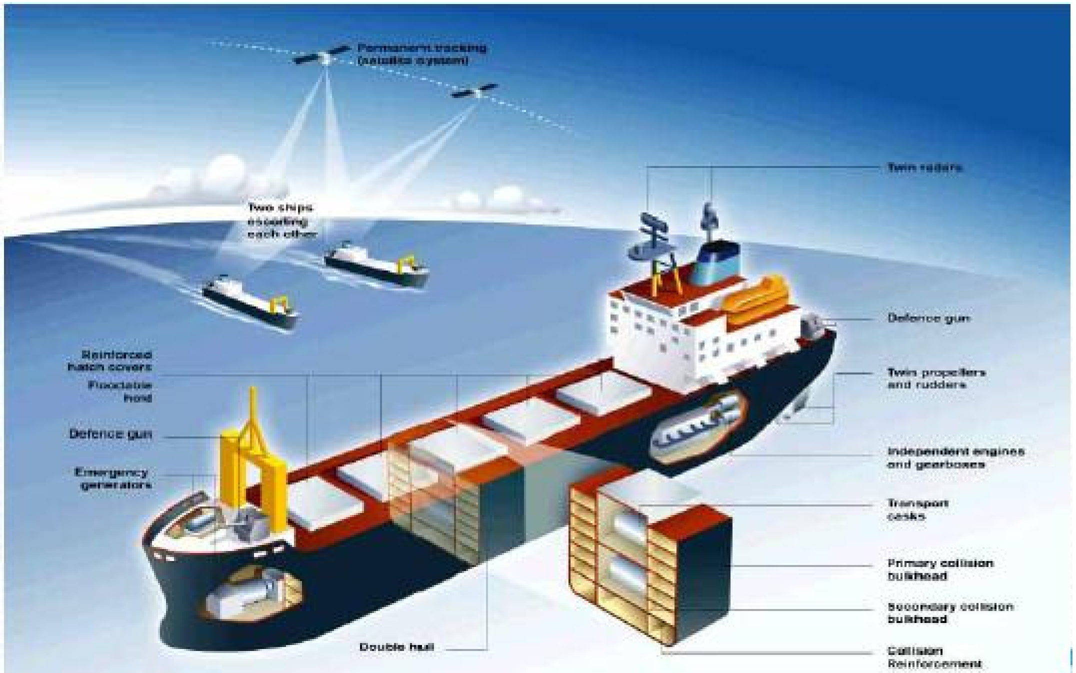

Figure 10: Robust vessels for transport of Spent fuel [16]

COLLABORATIONS ANTICIPATED FOR THE TRANSPORT

The Coalition of MNSR operators for conversion is a good avenue to obtain international assistance to enable the efficient transport of the irradiated fuel for the conversion activity. The interest expressed by the experts in the transport industry towards the conversion of MNSRs is indicative of their readiness to assist in ensuring safe transport of the irradiated cores to China.

RECOMMENDATIONS

The authors recommend that a similar cask and arrangement for transport of spent fuel from the various MNSR facilities to enable sharing of international best practices and collaboration. It is also recommended that the regulations on a single assembly of fuel be amended to allow for receipt of the fresh uranium oxide fuel and removal of uranium aluminium fuel during the replacement of the core.

CONCLUSION

The conversion of GHARR-1 is progressing steadily with emphasis placed on safety. The irradiated fuel shall be transported to China and the fresh fuel shall be obtained from CIAE. The activity shall performed based on the IAEA and RPB regulations on transport of radioactive materials.

ACKNOWLEDGEMENT

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