CURRENT STATUS OF THE NIGERIA MNSR (NIRR-1) AND FEASIBILITY FOR CONVERSION TO LEU

S. A Jonah and G.I. Balogun
Reactor Facility Section
Centre for Energy Research and Training
Ahmadu Bello University
P. M. B. 1014,
Zaria, Nigeria

ABSTRACT

NIRR-1 is the first nuclear reactor in Nigeria and it is sited at the Centre for Energy Research and Training (CERT), Ahmadu Bello University, Zaria. It was acquired specifically for neutron activation analysis, radioisotope production, training and research. Like all commercial Miniature Neutron Source Reactors (MNSR), NIRR-1 is a low power, tank-in-pool research reactor fueled with about 1 kg of HEU. The reactor, which was critical for the 1st time on 03 February, 2005 is presently in its first fuel cycle. In this presentation, a description of the main characteristic of the reactor is given, including details of areas of utilization and an overview of feasibility of conversion to LEU.

.

1. INTRODUCTION

The Nigeria Research Reactor-1 (NIRR-1), which is currently in its first fuel cycle was licenced to operate at 31.1 kW [1]. It is the 8th commercial miniature neutron source reactor (MNSR) designed by China Institute of Atomic Energy (CIAE). First criticality was achieved on 03 February 2004 and has been operated safely. It is specifically designed for use in neutron activation analysis (NAA) and limited radioisotope production. It is also suitable for teaching. In this paper, a description of the reactor is provided, including a summary of current utilization activities and the proposed core conversion studies.

2. REACTOR DESCRIPTION

The Nigeria Miniature Neutron Source Reactor named the Nigeria Research Reactor-1 (or NIRR-1) is a tank-in-pool type reactor with 90 % enriched uranium as fuel, light water as moderator and coolant, and metallic beryllium as reflector. As is implicit in the name, it is designed mainly to serve as a neutron source. The core is a cylindrical fuel assembly, approximately containing 347 fuel elements. NIRR-1 has only one central control rod which performs the functions of safe startup, shutdown, power regulation and reactivity control of the reactor. The reactor core assembly, surrounded by beryllium reflectors, is located at the bottom of the reactor vessel, which is suspended from the "I" beam structures that are embedded onto the reactor pool wall. The fuel element of the NIRR-1 is UAl_4 and the cladding is aluminium alloy. The fuel element is 248 mm in length with the active length being 230 mm. The diameter of the fuel meat is 4.3 mm and the ^{235}U loading in each fuel element is about 2.88 grams. Ten vertical aluminium alloy beam tubes are contained in the reactor vessel as irradiation channels. NIRR-1 has a nominal thermal power rating of 31 kW and a built-in clean cold core excess reactivity of 3.77 mk measured during the on-site zero-power and criticality experiments. The reactor can operate for a maximum of

4.5 hours at full power (i.e. equivalent to a thermal neutron flux of $1x10^{12}$ $n.cm^{-2}.s^{-1}$ in the inner irradiation channels). Under these conditions, the reactor fuel loading can run for over ten years with a burn-up of <1%. The main specifications of NIRR-1 are given in Table 1.

Table 1.Reactor Specifications

Reactor type	Tank-in-pool
Nominal thermal power	31 kW
Neutron flux (thermal, max.)	$1.02x10^{12}$ neutrons/cm^{2}.s
Coolant and moderator	Light water
Reflector	Metallic beryllium
Fuel type	U-Al alloy >90% enrichment
Number of control rods	1
Control rod material	Cd
Neutron irradiation channels	5 inner and 5 outer
Cd ratio of Au	2.12±0.02 (inner)
Thermal-epithermal flux ratio	19.2 ± 0.5 (inner)
Neutron temperature	333.7 K

3. Routine Utilization Procedures with NIRR-1

The irradiation facility of NIRR-1, depicted in Fig. 1, consists of five small rabbit tubes installed inside the Be annulus and they are designated as the inner channels. Between the Be annulus and the reactor vessel, three small and two large rabbit tubes known as the outer irradiation channels are installed. Presently, out of the ten irradiation sites, six are connected to the pneumatic transfer systems. There are two sets of transfer systems, the pneumatic transfer system type A, which is suitable for the irradiation of middle and long-lived nuclides. The other is a multi-functional transfer system simply known as the pneumatic transfer system B. It is used to send the sample into the reactor and retrieve it to a specified position such as detector, stripper or waste tank. It is specifically designed for NAA of short-lived nuclides and is suitable for cyclic NAA of nuclides with half-lives in seconds. In order to optimize utilization, experimental procedures were developed for the characterization of the irradiation channels. At present, the irradiation channels B2 and B4, which are referred to as reference irradiation channels have been characterized and the neutron spectrum parameters have been determined [2].

The associated facility for radioactivity measurements is a gamma-ray data acquisition system. The processing setup consists of a High-Purity Germanium (HPGe) detector, a Tennelec/Nucleus multi-channel analyzer (MCA) acquisition card, associated electronic modules all made by ORTEC and a personal computer. The full-energy peak efficiency curves of the gamma-ray spectrometry system have been determined at two source-detector positions using standard gamma ray sources [3]..

Routine irradiation and counting regimes, by which samples can be analyzed for trace, minor and major elements amounting to a total of 30-40 elements per sample depending on the matrix have been developed. In order to optimize the utilization of NIRR-1 and associated facilities, a detailed strategic/business plan have been developed [4]. The implementation of the strategic plan will contribute to the socio-economic development of Nigeria.

4. Core Management and Feasibility for Conversion

Fuel management of NIRR-1 is simple because like all MNSRs, it has a sealed core with one central control rod, which is used to start-up and shutdown the reactor. The method of checking the status of the fuel element is via periodic gamma-ray spectrometry of reactor water for fission products. As shown in Fig. 1, there are four reactivity regulators, which can be used to ensure that the excess reactivity falls within the safety limit of 3.5-4 mk during any core manipulation activities, most especially during the addition of Be shims. A special feature of the core of NIRR-1 is the inclusion of a special reactivity regulator (SRR) in an unconnected inner irradiation channel. It is made of Cd and was used to reduce the core excess reactivity from a value of 4.97 mk after fuel loading to 3.77 mk during the on site zero power and criticality experiments. In future, before the addition of Be shims when the core excess reactivity would have reduced to a value less than 3 mk, the SRR would be removed from the core to make-up for the loss of excess reactivity. With regards to core conversion, a scheme has been developed to carry out safety related calculations for reduced fuel enrichment of MNS reactors [5]. The scheme has been designed to work in a WINDOWS environment and it combines the

lattice code (WIMS) and core analysis code (CITATION) to determine the prompt temperature coefficient of reactivity, the overall temperature coefficient of reactivity and the safety reactivity factor for any specified value of fuel enrichment. Preliminary results show that to substantially reduce the enrichment of a typical MNS reactor to below 80% would necessitate a drastic review of the material composition of the core

5. CONCLUSION

NIRR-1 has been successfully installed and is being used for elemental analysis of soils and geological samples by the relative NAA method. A business/strategic plan to optimize utilization has been developed principally to expand the analytical capabilities of the facility for NAA. At present, there has been no core manipulation activity because the reactor is just over a year old. Results of a preliminary investigation on conversion to LEU using the deterministic codes WIMS and CITATION indicate a drastic review of material composition of core to achieve enrichment of below 80%. Further core conversion studies are to be undertaken using the transport code, the MCNP code under the auspices of the proposed IAEA/RERTR program for operators of MNSRs. This to strengthen the reactor physics groups and the provide tools for calculation at CERT.

References

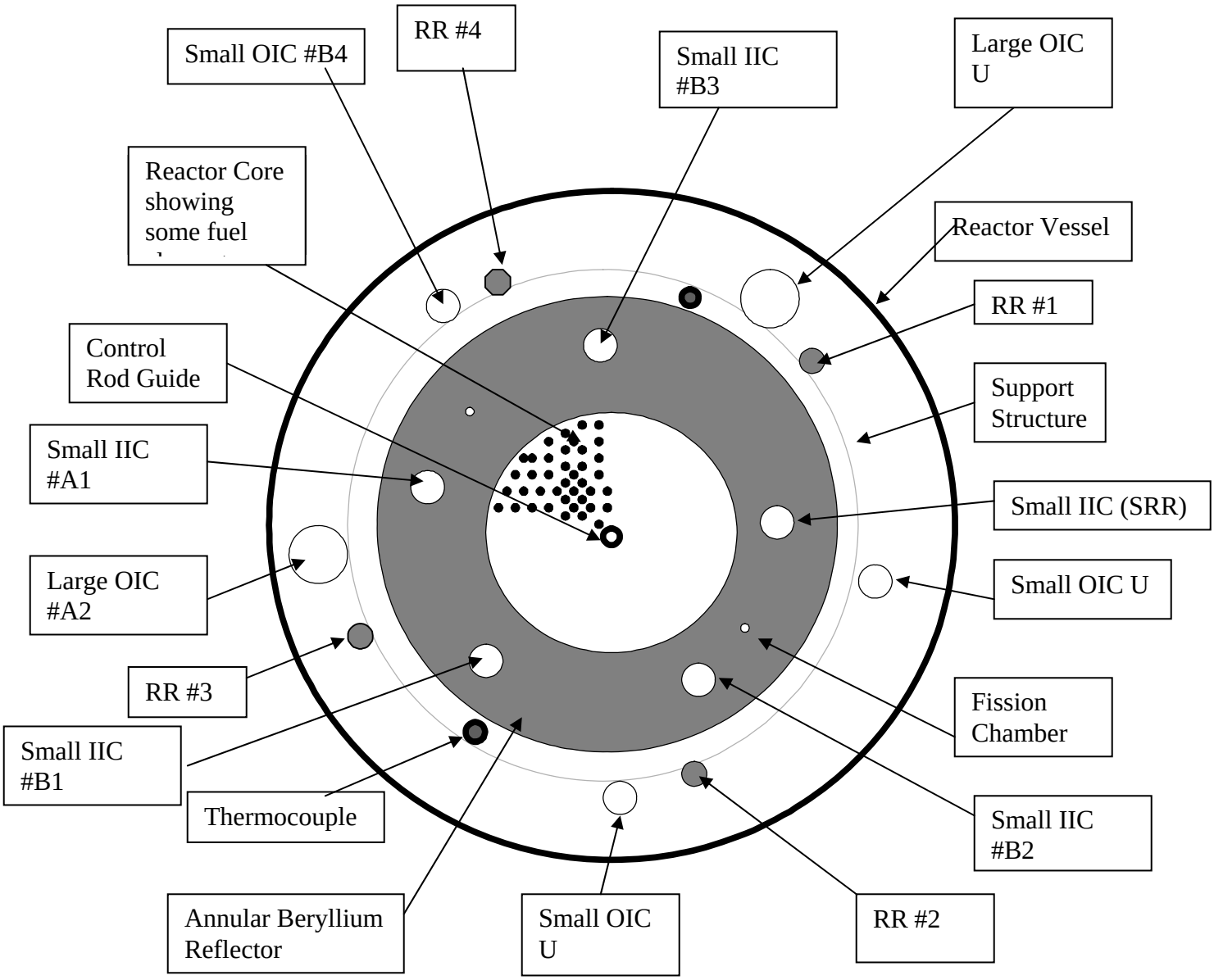
[1] G.I. Balogun, S.A. Jonah Results of On-site Zero-power and Criticality Experiments for the Nigeria Research Reactor-1, internal report CERT/NIRR-1/ZP/01(2004)

[2] S.A. Jonah, G.I. Balogun, I.M. Umar, M.C. Mayaki (2005) Neutron Spectrum Parameters in Irradiation Channels of the Nigeria Research Reactor-1 (NIRR-1) for the k_0-NAA Standardization Method, *J. Radioanal. Nucl. Chem.* 266, (2005), 83-88

[3] S.A. Jonah et al., Full-energy Efficiency Curves of NIRR-1 Gamma Ray Spectrometer at Different Source-Detector Positions, internal report, CERT/NIRR-1/NAA/01, (2004)

[4] CERT/NIRR-1/STP/01 Strategic utilization plan for Nigeria Research Reactor-1 (NIRR-1) 2004-2009, (2004)

[5] G.I. Balogun, On safety related calculations associated with miniature neutron source reactor core conversion studies, J. Appld. Sci & Tech. 8, (2003), 8-13



Key:

OIC-outer irradiation channel
IIC-inner irradiation channel
RR-reactivity regulator
U-unconnected
SRR-special reactivity regulator

Fig. 1: Lay-out of NIRR-1 core showing irradiation channels and control devices