Operational Experience and Programmes for Optimal Utilization of the Nigeria Research Reactor-1

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Abstract

The Nigeria Research Reactor-1 (NIRR-1) is the nation's first nuclear reactor and it is sited at the Centre for Energy Research and Training, Ahmadu Bello University, Zaria, Nigeria. It is a Miniature Neutron Source Reactor (MNSR) that attained criticality on February 03, 2004 and was licensed to operate at a maximum power of 31 kW three days a week in June 01, 2004. This presentation enumerates the measures put in place to ensure safe operation and adequate maintenance regime as well as the strategic plans for optimal utilization of the reactor. Some of these measures, which bothers on safe operation and sustainable maintenance culture that have been implemented include: strict adherence to the periodic preventive maintenance routines; standard procedures for pre-startup, startup and shut down procedures; provision of a quick access to reactor top to facilitate rapid response in case of emergency, especially in the case of rod-stuck incident. Similarly, on the basis of experience gained since the commissioning vis-à-vis the neutron flux spectrum characteristics of the MNSRs, experimental protocols are presented for the analysis of elements producing short-lived, medium-lived and long-lived activation products in geologic materials with negligible nuclear interferences especially for the analysis of Mg and Al in the presence of Al and Si respectively. Furthermore, research and development activities in core physics analysis and thermal hydraulics with regards to conversion from the current HEU core to a LEU core under the aegis of the IAEA Coordinated Research Project entitled "Conversion of MNSR to LEU" are outlined.

Introduction

In 1996, the IAEA approved the supply of a Miniature Neutron Source Reactor (MNSR) to the Government of Nigeria and in November 1997, construction of the reactor building started. The equipment and components of the 30 kW tank-in-pool nuclear reactor, called Nigeria Research Reactor-1 (NIRR-1) were installed between January to April 1999. Due to unforeseen circumstances, the fuel was not available for the subsequent commissioning of the reactor. On 17th December 2003 the fuel and the equipment for physical startup experiments were received and on February 3rd 2004, NIRR-1 was critical for the first time, thus the first nuclear research reactor in Nigeria became operational. NIRR-1 is currently in its 4th year of operation and has been fully deployed for training and research in different fields of endeavour aimed at socio-economic development of the country. A detailed safety measures used routinely in NIRR-1 facility has been discussed in a previous work [1], entitled “Measures aimed at enhancing safe operation of the Nigeria Research Reactor-1 (NIRR-1)” presented at the International Conference on Operational Safety Performance in Nuclear Installations, 30 November to 2 December, 2005 held at the IAEA Headquarters, Vienna Austria

Description of NIRR-1

NIRR-1 is a Miniature Neutron Source Reactor (MNSR) designed by China Institute of Atomic Energy (CIAE) [2]. First criticality was achieved on 03 February 2004 and has been operated safely [3, 4]. It is specifically designed for use in neutron activation analysis (NAA) and limited radioisotope production. NIRR-1 has a tank-in-pool structural configuration and a nominal thermal power rating of 31 kW. The current core of the reactor is a 230 x 230 mm square cylinder and fueled by $U\text{-}Al_4$ enriched to 90% in Al-alloy cladding. It has a total number of 347 fuel pins and three Al dummies in the fuel lattice. The length of the fuel element is 248 mm, the active length being 230 mm with 9 mm Al-alloy plug at each end. The diameter of the fuel meat is 4.3 mm and the ^{235}U loading in each fuel element is about 2.88 grams. The cladding is Al-alloy, whose thickness is 0.6 mm. There is only one Control Rod in NIRR-1 serving as shim rod, regulation rod as well as safety rod. The functions of reactor startup, steady-state operation, and shutdown are accomplished by moving the control rod. The Control rod is made up of a Cd absorber 266 mm long and 3.9 mm in diameter with stainless steel of 0.5 mm thickness as the cladding material. The overall length of the CR is 450 mm in length. A detailed description of the HEU core can be found in the final SAR [5]. With 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, mainly due to the large negative temperature feedback effects. Under these conditions, with the same fuel loading, the reactor can run for over ten years with a burn-up of <1% An MCNP model of the reactor fueled with HEU has been developed and benchmarked by measured data obtained during the on site zero power and power rising experiments [6]. Diagrams of NIRR-1 obtained from the MCNP model, showing core configuration and irradiation channels are displayed in Figures 1 and 2.

Operational Experience

NIRR-1 is operated exclusively using two 500 KVA diesel power generators installed onsite. In addition to this, the control console, the micro computer control system and the two rabbit systems are all connected to the power source through un-interrupted power sources for safety reasons. In the event of inadvertent release of total core excess reactivity, which may occur due to rod-stuck incident, reactor can be shut down by inserting Cd rabbits using either the rabbit systems or manually through a provision in NIRR-1, which allows for easy access to rector top. Reactor operators are licensed by the Nigerian Nuclear Regulatory Authority (NNRA) and are classified as Senior Operator (i.e. Class A), Operators (Class B) and Trainee Operators (Class C). The qualifications, functions and training requirements of these reactor personnel are enumerated in the final safety analysis report [5]. NIRR-1 was licensed by NNRA on June 01, 2004 to operate at maximum power of 31 kW for not more than 4½ hour per day, three days in a week (i.e. Tuesday, Wednesday and Thursday). The other two days (i.e. Monday and Friday) are for water purification and routine maintenance of the facility. From experience, during normal operation the reactor water temperature varies between 23 °C and 46 °C, whereas the temperature difference rises rapidly and attains a stable value due to the phenomenon known as 'insufficient natural circulation' A very important feature of NIRR-1 and similar facilities is the inherent safety due to limited core excess reactivity designed to be less than ½ β_{eff} and large negative total temperature coefficient of reactivity. This design feature of NIRR-1 limits the operation time to a maximum of 4½ hours at full power. Operational experience has revealed that for routine NAA works, it is sufficient to operate NIRR-1 at ½ power, which corresponds to a neutron flux of 5.0×10^{11} $n/cm^2.s$ in the inner irradiation channels. During steady state operation, the control rod is gradually withdrawn to compensate for reactivity loss due the large overall negative temperature coefficient of reactivity. Consequently, magnitude of the neutron flux remains constant during operation. The stability of the neutron flux is one of the hallmarks of NIRR-1 and similar facilities, which run on this same fuel loading for over 10 years. Since fuel is not modified at all for its entire core life time, the neutron spectrum in the irradiation channels does not change and the neutron flux is reproducible to within 1%. This allows convenient neutron activation analysis without the need to continually repeat the standardization measurements for all elements.

Programmes for Optimal Utilization

NIRR-1 was acquired for elemental analysis by NAA method. On the basis of the neutron spectrum characteristics in the irradiation channels, two regimes of irradiation depending on the half-life of product radionuclide have been adopted. For the analysis of elements via very short-lived nuclides (i.e. with $T_{1/2}$ in seconds), the cyclic NAA method is recommended in conjunction with Rabbit Type B. In general, for multi-element determination, the irradiation and counting regimes given in Table 1 should serve as a guide. For the analysis of the major elements, irradiation is performed in any of the outer channels (i.e. A2 and B4) to minimize nuclear interference with respect to the determination of Al in the presence of Si and for Mg in the presence of Al. Furthermore, organizational charts being used to achieve optimization in utilization and to conduct research in reactor engineering associated with conversion to LEU are presented in Figs. 3 and 4 respectively. Related to effective utilization of NIRR-1, the facilities are being used to prosecute two IAEA Coordinated Research Projects: "Development of Reference Database for NAA" through contract No. NIR/13278; and "Conversion of MNSR to LEU" through contract No. NIR/13933 respectively.

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This work is part of two IAEA Coordinated Research Projects: “Development of Reference Database for NAA” through contract No. NIR/13278; and “Conversion of MNSR to LEU” through contract No. NIR/13933 respectively

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Table 1 Irradiation and counting regimes that have been adopted for routine analysis with NIRR-1 facility

Neutron flux	T_{irr}	T_d	T_m	Element
8-10x10^{11} CNAA, B1 3-5 cycles	30-60s	3-5s	40-60s	Se, F, Rb, O, Sc
2-10x10^{11} Outer irradiation channels B4,A2	2-10m	1-10m	5-10m	Al, Mg, Cl, Ca, Cu, Ti, V, Br*, Sr, I*, S
		3-5h	5-10m	Na, K, Dy, Mn,
5x10^{11} Inner irradiation channels B2, B3, and A1	6-7h	2-3d,	20-30m	Na, K, As, Zn, Sb,Dy Br, Mo, La, Sm, Au, W, Ho, U, Ga, Lu, Ba, Yb
		10-15d	60m	Sc, Ce, Co, Cr, Cs Eu, Gd, Lu, Ba, Mo, Nd, Rb, Sb, Se, Ta, Tb, Th, Yb, Zn, Cd, Fe, Sr, Ag, Hf, Ir, Hg, Zr, Te, Os

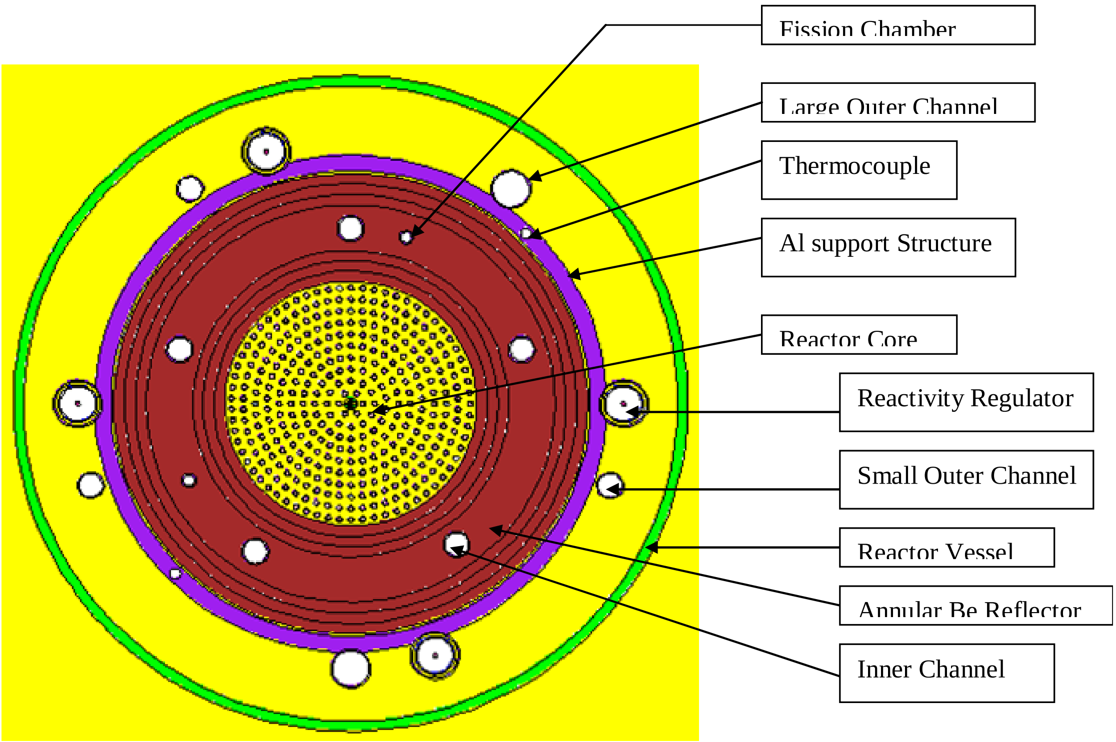

Fig. 1 A geometric diagram of NIRR-1 in the x-y plane from MCNP

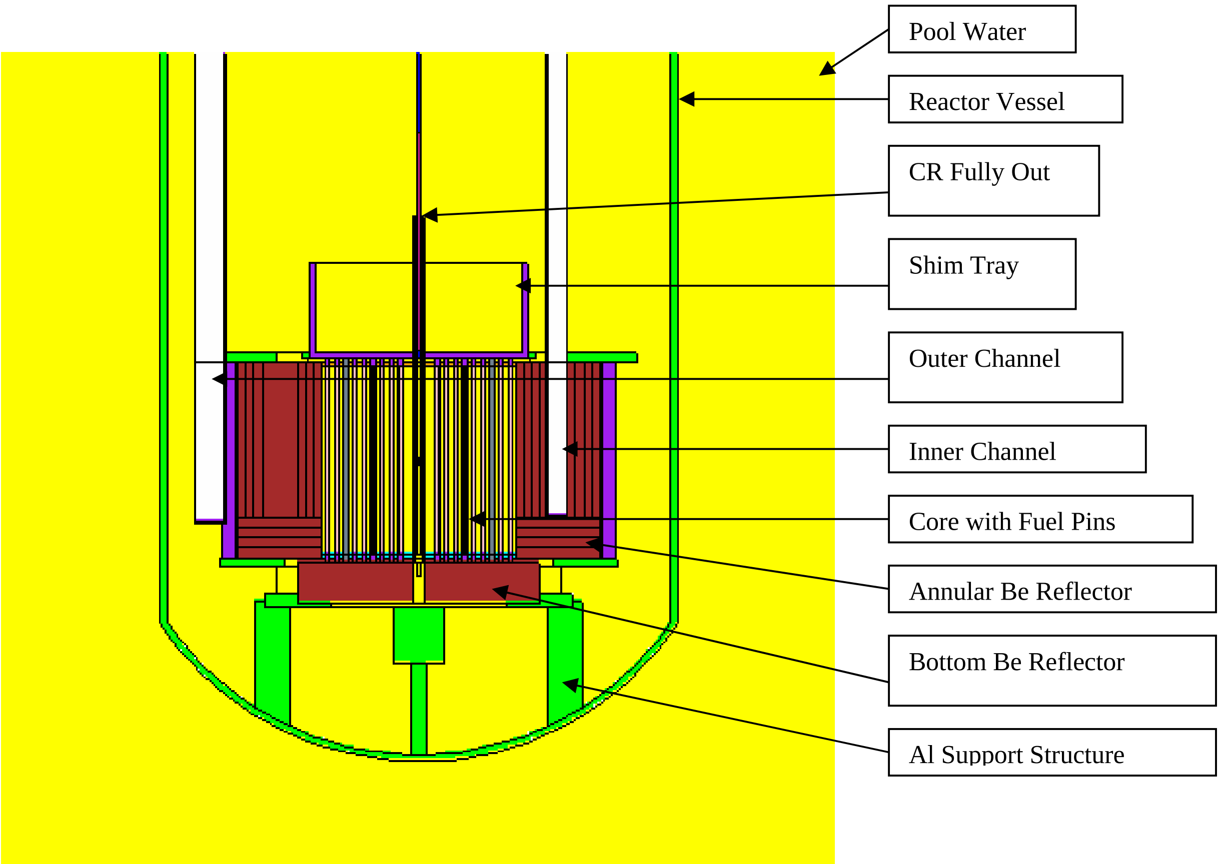

Fig. 2 An MCNP geometric representation of NIRR-1
with CR totally withdrawn

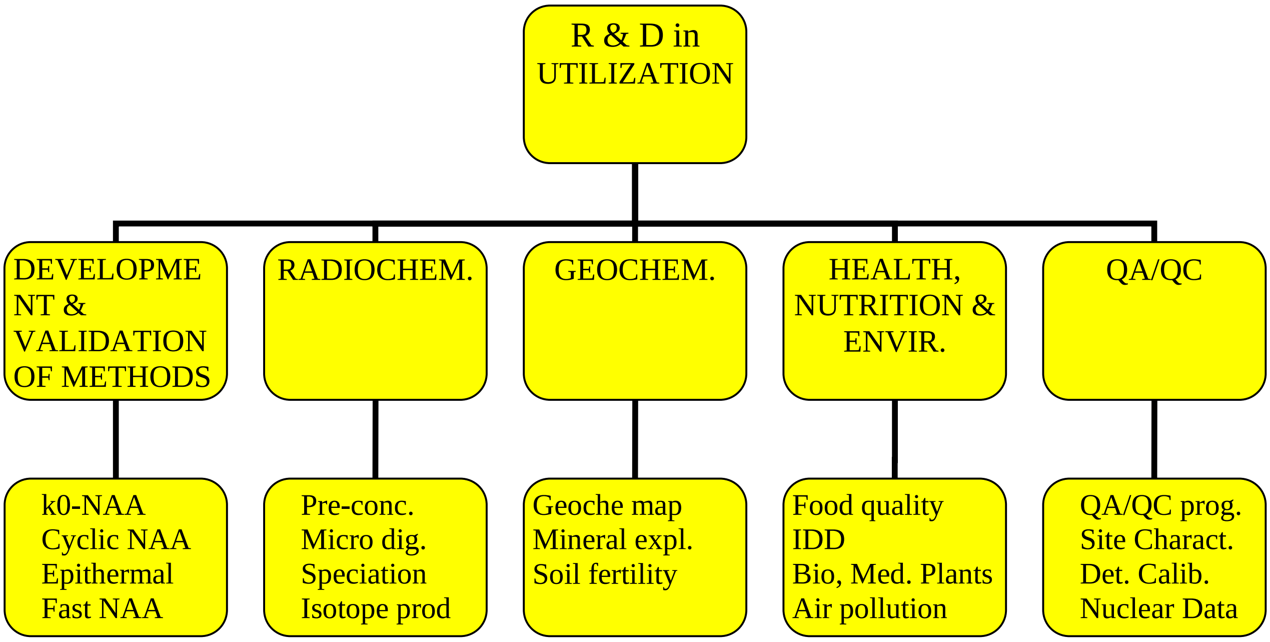

Fig. 3 Organizational chart for activities to optimize utilization

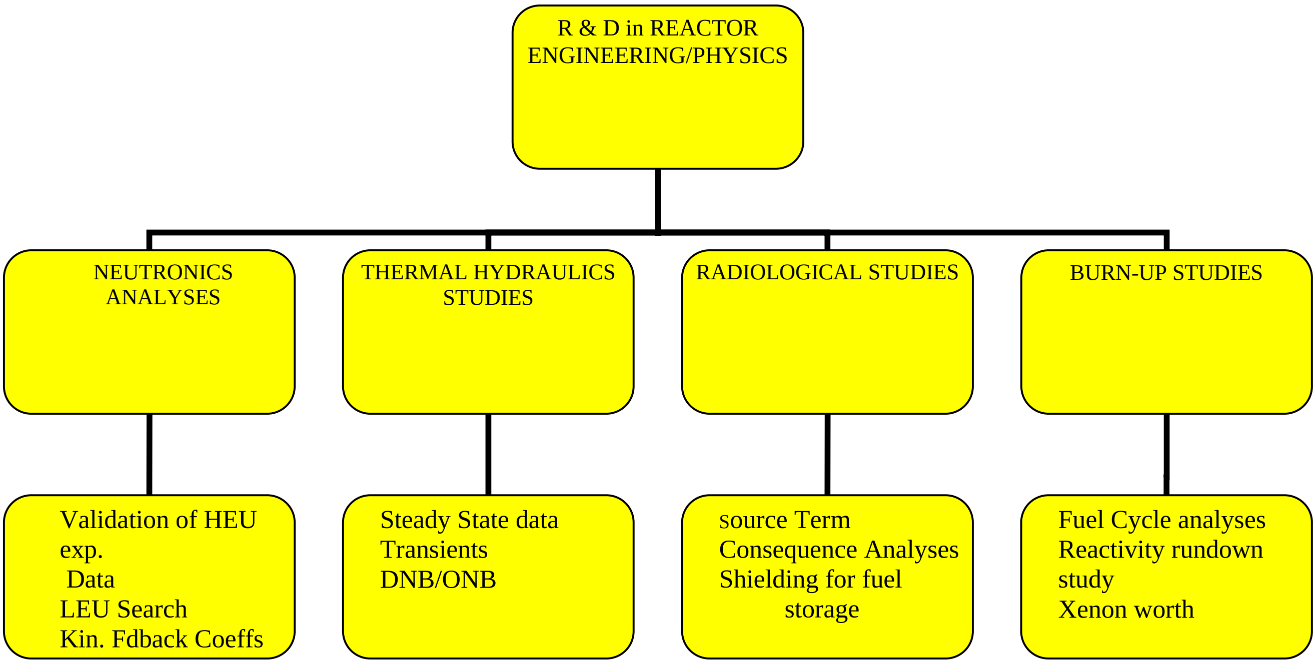

Fig. 4 Organizational chart for R & D activities in reactor engineering associated with conversion to LEU