# Research Reactors in Africa

IAEA
International Atomic Energy Agency

# Contents

In 2009, Africa passed a milestone of fifty years of involvement with nuclear technology, dating from the initial criticality of the Democratic Republic of the Congo's TRICO I research reactor (RR) at the University of Kinshasa. Egypt and South Africa soon followed, signalling a continental commitment to providing researchers, scientists, students and industries all across Africa access to modern nuclear analytical techniques and capabilities. Twelve RRs have been built in eight countries throughout the continent, all of which are Member States.

Africa's RRs are a vital component of the evolving role nuclear science and technology plays in society. These reactors have significantly contributed to the scientific progress made in a wealth of fields, appealing to a broad portion of the scientific community and the public. Aside from conducting research into nuclear data and improving our knowledge of the subatomic world, RRs provide the neutrons used to probe material structures for enhanced construction practices, to insert atomic impurities for the manufacturing of semiconductors, create radioisotopes for medical and industrial diagnostics as well as life-saving cancer treatments, examine environmental samples for tracking pollution, and assist farmers in crop selection and placement. Moreover, they are typically seen as the first step towards inaugurating a national nuclear power programme, and their work is essential to the entire lifetime of a power reactor through training of scientists and engineers and providing analytical tools for material damage studies, radiation shielding and waste containment. All of these services offered by RRs lead to safer and more efficient operation and maintenance procedures as well as improved safety culture and security. Though they retain much potential, RRs

Table 1. TYPES OF RESEARCH REACTORS IN AFRICA

| Country | Facility Name | Type | Thermal Power (kW) | Neutron Flux ($s^{-1}$ $cm^{-2}$) |
|---|---|---|---|---|
| **Algeria** | Nur | Pool | 1000 | $5.0\times10^{13}$ |
| **Algeria** | Es-Salam | Heavy water | 15 000 | $2.1\times10^{14}$ |
| ***Democratic Rep. of the Congo** | *TRICO II | TRIGA Mark II | 1000 | $3.0\times10^{13}$ |
| **Egypt** | ETRR-1 | Tank WWR | 2000 | $3.6\times10^{13}$ |
| **Egypt** | ETRR-2 | Pool | 22 000 | $2.8\times10^{14}$ |
| **Ghana** | GHARR-1 | MNSR | 30 | $1.2\times10^{12}$ |
| **Libya** | IRT-1 | Pool, IRT | 10 000 | $2.0\times10^{14}$ |
| **Morocco** | MA-R1 | TRIGA Mark II | 2000 | $4.4\times10^{13}$ |
| **Nigeria** | NIRR-1 | MNSR | 30 | $1.2\times10^{12}$ |
| **South Africa** | SAFARI-1 | Tank in pool | 20 000 | $2.8\times10^{14}$ |

* *At present on extended shutdown status.*

have already proven their ability to integrate and comply with the needs of various groups within the commercial, research and development, energy and service sectors.

Today, there are ten operating RRs across the African continent. These reactors cover a wide power range, starting with 30 kW up to 22 MW. Several common designs are represented, including the General Atomics Training, Research, Isotopes (TRIGA) model and the Miniature Neutron Source Reactor (MNSR), but there are other unique designs represented as well, as shown in Table 1. Whereas Morocco's new MA-R1 reactor can demonstrate the multiple uses of neutron activation analysis (NAA) and Algeria's facilities provide expertise in neutron studies of various materials, the versatility of South Africa's SAFARI-1, as one of the five main producers of the radioisotope molybdenum-99 (Mo-99) and a leader in neutron transmutation doping of silicon, and the specialities of Nigeria's Centre for Energy Research and Training as well as Ghana's National Nuclear Research Institute comprise comprehensive units for research, engineering and academic groups. Taken together, cooperation among the nuclear research facilities of Africa allows for the effective optimization of their capabilities while harmonizing research, operation and safety practices. Such programmes have the potential to facilitate commercially viable radioisotope production, more accurate and broader research endeavours, and more enriching and valuable training curricula. Efforts in Africa to integrate higher education in science can be seen with the increasing number of MSc and PhD theses that have been completed at least in part through research offered by these reactors.

With their geographical locations and capabilities, Africa's RRs are well positioned to further socioeconomic development. Increases in the standard of living of a given area tend to have a direct correlation with increased energy demands. Increasingly, countries seek nuclear power programmes as an alternative to the usage of fossil fuels and a narrow and vulnerable energy supply portfolio. South Africa is currently the sole African State with a nuclear power station, and it has intentions for greater capacity in the future. Some other Member States with RRs, e.g. Algeria, Egypt, Ghana, Morocco, and Nigeria, are seeking to use their experience as a stepping stone for a future nuclear power programme for their people in order to take advantage of Africa's vast uranium resources. Additionally, States without RRs such as Sudan and Tunisia are also interested in cultivating a nuclear infrastructure centred on their ongoing RR projects as the first step to commercial nuclear power, thereby creating a regional and, potentially, a continent-wide market for RR products and services.

This brochure provides self-descriptions of each of Africa's ten RRs, highlighting services that can benefit a wide range of stakeholders, including universities, hospitals, research institutes, State ministries, nuclear power plant staff, mining industries, and agricultural and environmental organizations. These reactors use modern analytical techniques in support of research, the manufacture of products for commercial applications and the training of future operators and researchers. Moreover, their complementary skills and facilities form a great capacity for cooperative efforts in each mission area, yet their individual experience and capabilities attest to a potential for tailored solutions when nuclear technology appears beneficial. Contact information for each facility is given in order for the reader to gain further and direct information on the multiple services available at the centres. This brochure provides only a snapshot as these RRs have much more to offer their countries and regions than can be adequately covered. By creating facilities where the brightest engineers and scientists can interact with commercial, industrial and governmental stakeholders, nuclear science and technology will provide the greatest benefit to society at large.

# ES-SALAM

*The Es-Salam research reactor building*

## 1. Technical Characteristics

The Es-Salam ("peace" in Arabic) reactor is a 15 MW multipurpose heavy water research reactor. It is located in Birine City which is situated 200 km to the south of Algiers, the Algerian capital. It is owned by the Commissariat à l'Energie Atomique (COMENA) and operated by the Centre de Recherche Nucléaire de Birine (CRNB). It was commissioned in 1992 and is used as an experimental and training tool in the field of nuclear techniques and reactor physics. It provides a high quality thermal neutron flux and is equipped with several irradiation positions.

### Technical features:

- Tank type research reactor of 15 MW power.
- Cooled and moderated by heavy water and uses graphite as a reflector.
- Six horizontal beam ports including a thermal column and 45 vertical irradiation positions.
- Maximum neutron thermal flux is 2 x $10^{14}$ $cm^{-2}$ $s^{-1}$.
- Operates continuously the three first weeks of the month with the last remaining week reserved for maintenance.

## 2. Products and Services

The Es-Salam research reactor is dedicated to the production of radioisotopes, scientific research, material testing and training of technical and scientific personnel. The research and analytical laboratories associated with the reactor have qualified personnel and state-of-the-art equipment capable of performing multiple concurrent projects.

### Irradiation

- Pneumatic system for neutron activation analysis and delayed neutron counting.
- Neutron radiography facility (static and dynamic) for processing and non-destructive testing of materials.

- NAA laboratories for trace elements determination by the direct comparison and k0 methodologies.

### Research and development

- Neutron diffraction facility equipped with a closed cycle coolant system using a helium liquefier for investigating material properties.
- Thermal hydraulic loops: high pressure/high temperature and low pressure/low temperature.
- Hot cells for destructive and non-destructive tests of irradiated materials.
- Core physics and thermal hydraulic calculations.
- Instrumentation and control design.
- Numerical modelling and simulation.
- Safety studies.
- Nuclear data analysis.
- Optimization of nuclear techniques.

### Education and training

- Reactor operation.
- Reactor physics and nuclear technology.
- Nuclear instrumentation and control.
- Nuclear safety and radiation protection.

Neutron activation analysis (NAA) continues to be one of the most utilized capabilities of the reactor. The laboratories dedicated to NAA have analysed both short, via a pneumatic system, and long lived radionuclides using traditional irradiation locations.

## 3. Future Capabilities

In order to expand the analytical capability the facility can offer, several new projects are in development. Analytical enhancements and developments for the future include:

- Upgrade the neutron diffraction facility in order to study residual strain for academic and industrial applications.
- Implement prompt gamma neutron activation analysis (PGNAA) for analysis of geological and atmospheric samples.
- Produce radioisotopes for medical and industrial applications.

## 4. Contact Information

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*Neutron diffraction facility*

*Delayed neutron laboratory*

*Neutron radiography facility*

*Four point probe*

# NUR

*NUR facility*

## 1. Technical Characteristics

The NUR reactor (acronym of Nuclear Uranium Reactor, also Arabic for "light") is an open pool 1 MW research and training reactor. Commissioned in March 1989, it is located near Algiers, the capital of Algeria.

It is mainly used for training of operators and nuclear engineering students and in the development and utilization of nuclear analytical techniques and applications that support socioeconomic development.

The primary missions of the reactor are:

- Training of operators and university students.
- Studies and experiments in physics and reactor technology.
- Development and utilization of nuclear techniques.
- Neutron activation analysis.
- Neutron reflectometry.
- Neutron radiography.
- Small angle neutron scattering (SANS).
- Production of radioisotopes and radiopharmaceuticals (at laboratory scale).

### Technical features:

- Pool type, 1 MW research reactor.
- Fuelled with MTR plate-type fuel enriched to 19.75%.
- Cooled and moderated by light water.
- Graphite reflector.
- Neutron flux of $10^{13}$ $cm^{-2}$ $s^{-1}$.
- Four radial and one tangential beam tubes.
- Two vertical irradiation positions.
- Two fast pneumatic transport systems.
- One hot cell and one transfer cell.

## 2. Products and Services

Various research and development activities in the field of nuclear engineering are conducted by scientists and technical staff to enhance the utilization of the facility. The NUR reactor is a valuable tool at both the national and regional level. It can be used to enable the implementation of research and development programmes and training in the fields of nuclear reactor operations and nuclear engineering which will contribute effectively to the introduction of a national nuclear power programme in Algeria. These activities include applications of:

### Education and training

- Nuclear engineering.
- Reactor physics and operation.

### Research and development

- Core physics and thermal hydraulic calculations.
- Instrumentation and control design.
- Numerical modelling and simulation.
- Safety studies.
- Nuclear data analysis.
- Nuclear technique optimization.
- Material science.

### Irradiation

- Neutron activation analysis.
- Radioisotope production (at laboratory scale).
- Quality control of radiopharmaceuticals.
- Technetium kits.
- In vivo and in vitro radiopharmaceuticals.
- Monoclonal antibodies.
- Neutron beam applications (SANS, reflectometry, neutron radiography, etc.).

## 3. Future Capabilities

To optimize the reactor's use and availability of neutron techniques and applications, several projects are ongoing or planned, mainly:

- Studies on the use of neutron guides to improve the signal to noise ratio around the reflectometer and SANS spectrometers.
- Increased utilization of functional and proven nuclear techniques, e.g. NAA, neutron radiography.
- Finalization of projects (e.g. Tc-99 kits, production of I-131 and Sm-153, in vitro kits) and implementation of procedures for good manufacturing practices, evaluation and validation (QA/QC) that will enable routine production.

## 4. Contact Information

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*Reactor block*

*Reactor core*

*Universal cell*

*Technetium kits*

# TRICO-II

*General Commission of Atomic Energy*

## 1. Technical Characteristics

The TRICO-II research reactor is located in Kinshasa, the capital of the Democratic Republic of the Congo, on the western border of the country. TRICO-II is a TRIGA Mark II type reactor owned by the Commissariat Général à l'Energie Atomique (CGEA) and operated by the Centre Régional d'Etudes Nucléaires de Kinshasa (CREN K). Its predecessor, TRICO-I, a 50 kW reactor, was fully operational at this site from 6 June 1959 to 29 June 1970. This reactor was shut down in 1970 and dismantled but has not yet been decommissioned.

On 24 March 1972, TRICO-II achieved its initial criticality as the second and more powerful Congolese RR. It was constructed under General Atomics specifications and supervision with the assistance of experts from the Centre for the Study of Nuclear Energy (SCK/CEN) in Mol, Belgium, during 1970 and 1971. Since November 2004, TRICO-II has been in an extended shutdown condition.

### Technical features:

- Pool type, 1 MW TRIGA research reactor.
- Nominal transient peak power of 1600 MW in pulse mode.
- TRIGA standard, stainless steel clad fuel enriched to 20%.
- Cooled and moderated with demineralized light water.
- Primary and secondary forced water cooling systems.
- Graphite reflector.
- A thermal column with a maximum flux of $10^{11}$ $cm^{-2}$ $s^{-1}$ and a central experimental tube with a flux of $10^{14}$ $cm^{-2}$ $s^{-1}$.
- Ra-Be neutron source.
- Five neutron flux measurement channels with various detectors.
- Three axial and one tangential neutron beam tubes.

## 2. Products and Services

The reactor TRICO-II is a thermal neutron source for scientific research, training, radioisotope production and material characterization. Horizontal neutron extraction beam tubes are dedicated to diffraction and radiography studies.

### Research and development

- Tracer studies, reactor physics, reactor tank corrosion repair.
- Nuclear analytical techniques.

- Geochemistry and hydrochemistry, particularly using raw phosphate ore towards soil fertility studies and mineral exploitation.
- Precious metal recovery from wastes of electrolytic refinery plants.

## Services and products

- Multi-elemental analysis of environmental and food samples using NAA techniques, specifically k0 and derived integrated NAA (INAA).
- Precious metal content characterization of exported ingots of copper, cobalt, zinc and other elements.
- Production of radioisotopes such as P-32, Au-198 and Tc-99m for medical, industrial and agricultural applications.
- Production of radiotracers for the gold mining industry.

## Education and training

- Training in reactor operation and reactor physics.
- Preparations for a national nuclear power programme.
- Educational projects and research theses using nuclear science and technology for university and other institute students.

## Health services

- In vivo and vitro diagnostics for various cancers, nutrition and infectious diseases.
- Fertility research in animals and humans.

# 3. Future Capabilities

- Restart the TRICO-II research reactor following the currently scheduled outage.
- Upgrade radioisotope production unit for medical and industrial applications.
- Implement neutron radiography and diffraction facilities.

# 4. Contact Information

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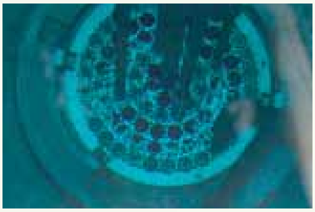
*TRICO II reactor*



*Reactor core*

*Hot cell for RI processing*

*Measuring room*

*Diagnostics using a gamma camera*

# ETRR-1

*ETRR-1 facility*

## 1. Technical Characteristics

Egypt's first reactor, the Experimental Training Research Reactor-1 (ETRR-1), achieved its initial criticality in February of 1961, inaugurating the nuclear age in North Africa. A Soviet design VVR type light water reactor, it is based at the Inshas Nuclear Research Centre outside of Cairo and has been used for nearly five decades of nuclear physics and material experiments. Subsequent to developing the initial phase of the country's nuclear infrastructure, the reactor was shut down in the 1980s and modernized with assistance from the IAEA geared towards its long term operability. This technical cooperation programme extended throughout the 1990s and enhanced the reactor's already considerable experimental facilities. Today, the small reactor's operation profile ranges from isotope production, nuclear physics, and chemical and biological research to extensive material testing.

### Technical features:

- Tank type, 2 MW VVR training reactor.
- Fuelled with 10% enriched uranium.
- Cooled and moderated by light water, which also serves as the reflector.
- Maximum fast flux of $3.6 \times 10^{13}$ $cm^{-2}$ $s^{-1}$, maximum thermal flux of $1.5 \times 10^{13}$ $cm^{-2}$ $s^{-1}$.
- Nine horizontal beam channels with a maximum flux of $5 \times 10^{8}$ $cm^{-2}$ $s^{-1}$.
- Horizontal channels contain four Fourier diffractometers, including the Cairo Fourier Diffractometer Facility (CFDF) installed in 1996.
- Eight vertical beam channels with a maximum flux of $8 \times 10^{12}$ $cm^{-2}$ $s^{-1}$.
- Vertical channels support radioisotope production.

## 2. Products and Services

Since its upgrade and modernization, ETRR-1 has provided neutrons for experiments in material science, biological irradiation, chemical testing, and physics reactions. Particularly in material investigation, the CFDF and Fourier reverse time of flight methods support high resolution measurements of diffraction spectra under high temperature and pressure conditions for characterizing material behaviour and textural changes, which have proved useful in a number of industrial applications. Furthermore, recent upgrades including a specialized interface card and software have decreased the necessary measurement time and neutron economy. ETRR-1 has also enabled some radioisotope production and a significant number of academic thesis projects.

### Research and development

- Studies of textural changes following certain metallurgical processes, notably residual stress in welds.
- Feasibility studies of Plexiglass as a substrate for neutron mirrors.
- Irradiation of chemical and biological samples.
- Studies of steady state, neutron, and reactor physics.
- Research into solid and liquid radioactive waste treatment and storage as well as shielding.

### Products and services

- Production of radioisotopes such as I-131 and P-32.
- Neutron scattering and diffraction services with analysis.
- Computerized neutron tomography.

### Education and training

- Experiments have been conducted for numerous Master's and PhD level theses from Egyptian universities.
- International cooperation among students and researchers from Saudi Arabia, Lebanon, Kuwait and Sudan.

*Reactor control panel*

## 3. Future Capabilities

The staff of ETRR-1 is committed to providing quality educational and research opportunities to the wider Arab and international communities. However, much of the focus for the future will consist of devising a business plan to market our many services and improve the reactor's utilization. ETRR-1 staff will:

- Develop a business plan with a national and regional marketing strategy for services and radioisotopes.
- Upgrade safety protocol for operational safety and comprehensive maintenance.
- Harmonize facilities to the requirements of markets.
- Pursue further cooperation throughout Africa, the Middle East and Southern Europe.

## 4. Contact Information

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# ETRR-2

*Inshas nuclear complex*

## 1. Technical Characteristics

The relatively new multipurpose ETRR-2 facility (constructed in 1992 and first critical in 1997) is located at the Inshas Nuclear Complex in Cairo. It incorporates important lessons from previous research reactor designs and utilization programmes. During the design process INVAP S.E. of Argentina and the Egyptian Atomic Energy Authority evaluated and envisioned the potential usefulness of the facility based on experience and international studies concerning the advantages of a medium flux reactor. The key aspects of the ETRR-2 design are its flexibility and potential for modification to accommodate future needs and technology.

### Technical features:

- Open pool type research reactor of 22 MW thermal power with a beryllium reflector and low enriched uranium (LEU) fuel.
- 26 irradiation positions with a maximum core thermal flux of $2.73 \times 10^{14}$ $cm^{-2}$ $s^{-1}$.
- Cooled and moderated by light water .
- The reactor is currently operable and licensed for operation at full power.
- Three radial and one tangential beam tubes.
- Two fast pneumatic transport systems for fast irradiation.
- Several hot cell facilities at the reactor for radioisotope processing, irradiated sample handling, inspections and material testing.
- A wide range of experimental and production facilities are installed to meet the requirements of various utilization groups including universities, research institutes, industry and medical organizations.

## 2. Products and Services

The reactor can support continuous full power operations for 19 consecutive days before refuelling. The staff is qualified to support longer operation times and trained to perform all operations listed below at the highest safety and quality standards. These activities and studies include:

### Research and development

- Neutron scattering experiments (diffraction and time-of-flight) both for fundamental material research and various applications.
- Computerized neutron tomography.
- Shielding experiments.

### Irradiation

- Analytical analysis of different samples (INAA, NAA) for geological, environmental and medical applications.
- Production of I-131 and P-32 for medical purposes and other special radioisotopes including Mo-99, Cr-51, Ir-192 and I-125.
- Semiconductor production using neutron transmutation doping for the irradiation of silicon ingots (diameter 5 inches/length 11 inches).
- Gem stone treatment (e.g., topaz production, ≈200 kg per month).
- Neutron radiography and material testing for industry.

## Education and training

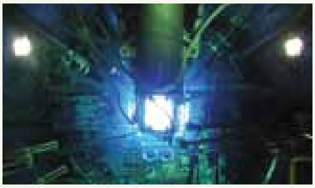
- Training activities and workshops in radiation protection, quality assurance and quality control, fuel management, core calculations and modelling in support of new research reactor applications.
- Education and training for university students.

## Other

- Installation of sealed sources in gamma cameras for nuclear imaging.
- Maintenance of the gamma cameras and radiation protection devices.

Neutron tomography and isotope production in particular play an essential role for the development of Egypt's national medical service. For example, iodine-131 is widely used to diagnose and treat thyroid cancer and other abnormal conditions such as hyperthyroidism, while phosphorus-32 is utilized for control over excess red blood cells produced in the bone marrow caused by polycythemia vera disease.

Silicon ingots also carry a high importance for the semiconductor industry and are widely used in their commercial production, while another important area of activities is related to education, training and nuclear capacity building. This is of particular significance for Egypt, which has recently announced plans to embark on a nuclear power programme around 2020. Present reactor stakeholders vary from research institutes and universities to industrial and medical organizations. Still, the capabilities of the ETTR-2 are constantly increasing as the potential for contribution to development and modernization remains high.

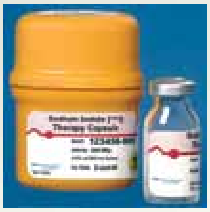


*Main pool*

*Material testing hot cell*

*Beam tubes*

*London Blue Topaz coloured by irradiation with neutrons*



*Iodine-131 medication*

*Silicon ingots for semi-conductors*

# 3. Future Capabilities

The administrators of the reactor and respective Egyptian authorities fully support further utilization and implementation of a strategic plan for enhancing the sustainable development of ETTR-2. Projected modifications are as follows:

- Increase in capacity for Mo-99 production based on neutron capture.
- Development of real-time digital neutron radiography.
- Installation of a PGNAA and SANS facilities.
- Further development of neutron transmutation doping of the silicon facility.
- R&D in boron neutron capture therapy.

# 4. Contact Information

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# GHARR-1

*GHARR-1 research reactor building*

## 1. Technical Characteristics

The MNSR in Legon-Accra is a low power research reactor and is similar in design to the Canadian SLOWPOKE reactor. The MNSR reactors, designed and built by China, are presently being operated in a number of countries including China itself, Ghana, Iran, Nigeria, Pakistan and Syria, and are considered as an excellent tool for NAA and human resource development in nuclear science and technology. The construction, commissioning and operation of this reactor have been subjected to the system of authorization and inspection developed by the regulatory authority, the Radiation Protection Board, with assistance from the IAEA. International Safety Assessment peer review and safety inspections have confirmed a high level of operational safety of the reactor since it started operating in 1994.

### Technical features:

- Tank-in-pool type 30 kW research reactor facility.
- High enriched uranium (HEU) fuel is currently used.
- Small core is heavily reflected on the sides and the bottom with a beryllium alloy material.
- Cooled and moderated by light water in natural convection.
- A single cadmium control rod clad with stainless steel material is used for power regulation, compensation of fuel consumption, reactor startup and shutdown.
- The reactor has ten irradiation sites arranged inside and outside the side annular reflector, providing the capability for multiple sample irradiations at different flux levels.
- Maximum thermal neutron flux is $1.0 \times 10^{12}$ $cm^{-2}$ $s^{-1}$.
- Two gamma spectroscopy systems plus detector equipment for qualitative and quantitative measurements.
- Multi-elemental sample analysis facilities.
- Education and training facilities for university students and nuclear engineers.

## 2. Products and Services

The GHARR-1 research reactor is utilized in support of oil and aluminium manufacturing industries, research institutions, universities, government regulatory agencies and various NGOs and individuals. The services carried out have included:

### Research and development

- Reactor physics, nuclear reactor core calculations and application driven design, analysis and experiments.
- Nuclear analytical techniques and nuclear waste management.
- Geochemistry and hydrochemistry, soil fertility studies and mineral exploitation.
- Radiation transport physics and shielding research.

### Irradiation

- Multi-elemental analysis of materials using NAA.
- Analysis of borehole water, sediments and water from streams and rivers in mining areas.
- The production of some radioisotopes as tracers for petrochemical and mining industrial applications.

### Education and training

- Training nuclear scientists in reactor operation and management and reactor physics and preparing them for a potential national nuclear power programme.
- Education of university and other tertiary students through projects and research theses in nuclear science and technology.

NAA is widely applied for multi-element non-destructive analysis in earth sciences (geology, geochemistry, and geophysics), environmental monitoring and pollution assessments (air, water, and soil), food and agriculture, health, medicine and pharmaceuticals, biology, materials science, etc. In order to define our origins, NAA in conjunction with both conventional and Compton suppression counting are utilized in the determination of concentrations of trace elements in ancient pottery excavated from some major archaeological sites in Ghana.

Environmental pollution studies using environmental samples such as sediments, soil, water and biological indicators like lichens are some of the past and ongoing research projects being carried out using the GHARR-1 facility. One of the most interesting environmental studies being carried out at the facility was the use of lichen transplants for monitoring vehicular traffic emissions in the country.

## 3. Future Capabilities

The process of modification and development is still ongoing. In particular, R&D studies undertaken with international cooperation are dedicated to the conversion of the reactor core from HEU to LEU. Other future updates include:

- Increase of the number and variety of short-lived radioisotopes produced.
- Installation of a new irradiation site (slanting tube) to allow the use of the larger samples (~5.0 g). Large sample NAA will be applied for a sensitivity increase in NAA under a low flux of neutrons.
- Support of forensic investigation for security agencies by the use of nuclear analytical techniques.
- Further increase of INAA utilization for archaeological studies.
- Installation of the side looking detectors along with the integration of the gamma ray spectrometer into a scanning device will allow the rotation of cylindrical samples around the vertical axis during counting and thereby reduce geometrical effects.

## 4. Contact Information

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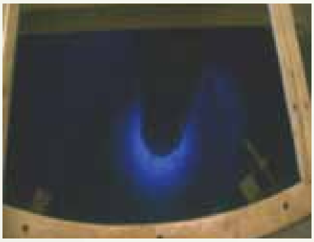

*Reactor in operation*

*Reactor vessel head*

*Slanting tube for large sample NAA*

*Analysis of ancient pottery using INAA*

*Quality control of petroleum products*

# IRT-1

*Tajoura Nuclear Research Centre*

## 1. Technical Characteristics

The IRT-1 research reactor was constructed at the Tajoura Nuclear Research Centre in Tajoura in 1979 and began operation in 1981. Its fuel was converted in 2006 from HEU to LEU. The facility continues to be the cornerstone of the national programmes for radioisotope production, research in nuclear physics, and nuclear education and training. The Centre is operated by an expert staff equipped with numerous laboratories, divided into focus areas such as nuclear physics, solid state physics, neutron physics, materials science, activation analysis, radiation biophysics, radiochemistry, plasma physics, mass spectrometry and radiation protection and health physics, as well as a neutron generator laboratory containing an NG-150 high voltage accelerator. There is an agreement with Al Fateh University in Tripoli for the training of students and to conduct MSc projects in addition to the IRT-1's own advanced laboratory course and several workshops on research reactor utilization and radiation protection.

### Technical features:

- 10 MW, pool type research reactor.
- Uses 19.7% enriched LEU fuel in IRT-4M cells.
- Cooled and moderated by light water.
- Beryllium reflector.
- Maximum neutron flux of $10^{14}$ $cm^{-2}$ $s^{-1}$.
- Eleven horizontal channels, one is a double open-ended channel with a diameter of 150 mm.
- Fifty sample irradiation positions.
- A critical facility has been constructed as a mockup of the reactor, with a maximum neutron flux of $10^{7}$ $cm^{-2}$ $s^{-1}$.
- NAA Unit possesses both a short irradiation facility and a laboratory for the analysis of long-lived isotopes.

## 2. Products and Services

### NAA and irradiation activities

- An irradiation facility and an analysis laboratory are provided for NAA activities.
- The NAA Unit has been certified through several IAEA proficiency tests.

- NAA has been used for food and environmental surveys, such as elemental analysis of fish bones and marine algae.
- INAA has revealed the elemental content of blood samples from tuberculosis patients.

### Radioisotope production

- Isotope production has been central to the facility's operation, yielding P-32, Tc-99m and others.
- I-131 has been produced for local hospitals and Na-24 has been used by the soap industry to improve chemical mixing.
- Br-82 produced has been used by the oil industry as a radiotracer.

### Material science and research

- The Materials Science Unit has examined the nuclear structure of some elements and investigated the use of local materials as radiation shielding.

### Education and training

- The research reactor and associated labs regularly conduct MSc and nuclear medicine projects and give university students at all levels opportunities to conduct experiments for laboratory courses.
- The Centre has conducted an advanced laboratory course for three years.
- Workshops on research reactor utilization, radiation protection and naturally occurring radioactive materials.

## 3. Future Capabilities

Although the Centre relies upon government funding, recently a business plan for self-sufficiency has been developed. This plan involves seeking opportunities to provide our many services and approaching end users for business undertakings. The NAA and Radiation Protection Departments have successfully combined in support of this programme by conducting food monitoring programmes and issuing customer clearance letters for import and export products. The goal is also to:

- Find more accessible markets for nuclear techniques.
- Upgrade the PTS for short irradiation services.

## 4. Contact Information

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*IRT-1 research reactor*


*Reactor core*


*Experimental Equipment*


*Gamma spectroscopy laboratory*


*NAA laboratory*

# MA-R1

*Reactor facility*

## 1. Technical Characteristics

The research reactor facility is located at Centre d'Etudes Nucléaires de la Maâmora (CENM), located approximately 25 kilometres north of the city of Rabat. The reactor building includes the TRIGA Mark II research reactor with an initial power level of 2 MW(th), and is equipped for a planned future upgrade to 3 MW(th). The CENM with its TRIGA reactor and fully equipped laboratories gives the Kingdom of Morocco its first nuclear installation with extensive capabilities. These include the production of radioisotopes for medical, industrial and environmental uses; metallurgy and chemistry; implementation of nuclear analytical techniques such as NAA and non-destructive examination techniques; as well as carrying out basic research programs in solid state and reactor physics. The TRIGA Mark II research reactor at CENM achieved initial criticality on 2 May 2007 and its construction culminated with the successful completion of full power endurance testing on 6 September 2007.

### Technical features:

- Steady state power rating of 2 MW(th).
- Fuelled by TRIGA standard, 8.5% uranium content, enriched less than 20%.
- 101 fuel elements and 5 B4C control rods.
- Reactor cooling by natural convection.
- Rotary specimen rack assembly capable of irradiation of 79 samples simultaneously.
- Pneumatic transfer system.
- One central experimental tube (max. flux $4 \times 10^{13}$ cm$^{-2}$ s$^{-1}$).
- Thermal column.
- Three radial beam ports, one tangential.
- Hexagonal and triangular cut outs.

## 2. Products and Services

The ability to perform advanced neutron techniques and administer complex training programmes has been recently demonstrated. For example, NAA has been successfully performed for soil and geological mapping, and pollution assessments and neutron diffraction has been used for material studies. The overall agenda also encompasses both radioisotope production and education and training programmes. The following summarizes major activities around the RR facility:

### Research and development

- Material sciences.
- Neutron tomography.

### Services and products

- INAA, NAA for geological and environmental samples.
- Production of I-131, P-32 and other radioisotopes for medical and industrial applications.
- Neutron transmutation doping for semiconductor manufacturing.
- Gem stone treatment.
- Neutron radiography.

### Education and training

- Training, workshops in radiation protection, reactor physics and in nuclear science and technology.
- Education and training for university students and professionals.

## 3. Future Capabilities

- Possibility to upgrade the power to 3 MW.
- Installation of a SANS facility.
- Installation of a PGNAA facility.

## 4. Contact Information

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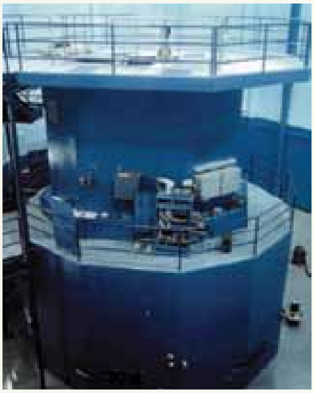

*MA-R1 reactor*

*NAA laboratory*

*Operators at hot cells*

*Hot cell for radioisotope production*

*Quality control laboratory*

# NIRR-1

Entrance to the NIRR-1 building

## 1. Technical Characteristics

The Nigeria Miniature Neutron Source Reactor, named Nigeria Research Reactor-1 (NIRR-1), is a low power research reactor with a nominal thermal power of 31 kW and a maximum flux of $1 \times 10^{12}$ $cm^{-2}$ $s^{-1}$ in its inner irradiation sites. It is a small, compact and safe reactor that employs HEU as the fuel, light water as the moderator/coolant, and beryllium as the reflector. This MNSR was designed for use in universities, hospitals and research institutes mainly for NAA, limited production of short-lived radioisotopes and training.

The reactor is a pool type owned by the Nigeria Atomic Energy Commission with the assistance of the IAEA. It is located at the Centre for Energy Research and Training (CERT) at Ahmadu Bello University in Zaria, Nigeria.

### Technical features:

- 30 kW thermal power.
- Neutron flux: ~$10^{12}$ $cm^{-2}$ $s^{-1}$.
- One central control rod used for regulating power level, compensating for fuel burnup and for startup and shutdown.
- The core consists of 347 fuel elements arranged in a fuel cage of 10 multi-concentric layers inside an annular beryllium reflector and rests on a lower beryllium reflector plate.
- The fuel elements are all enriched uranium–aluminium alloy extrusion, clad with aluminium.
- Cooled by light water flow through natural convection.

## 2. Products and Services

The reactor is designed mainly for NAA, and this versatile analytical technique, with the multichannel analyser computer system, is being used in support of many research, commercial irradiation and teaching projects. Auxiliary systems such as pneumatic transfer systems provide for additional NAA capabilities. One, known as type A, is suitable for irradiation for medium and long periods. Type B, a multifunction capsule transfer system, is coupled to four irradiation tubes. The reactor is also used for training in nuclear physics and nuclear engineering courses at CERT such as reactor statics, reactor dynamics, thermal hydraulics, health physics and radiological protection.

## Research and development

- Neutronics analyses and thermal hydraulics studies.
- Burnup calculations and fuel cycle analyses.
- Effects of core excess reactivity and average temperature on maximum operable time of NIRR-1.
- Effects of temperature and control rod position on spatial neutron flux distribution.
- MNCP simulation of permanent Cd-lined irradiation channel for improved utilization of commercial MNSR facilities.
- Resolving discrepancies between measured and estimated half-life of some radionuclides.
- Measurements and evaluation of nuclear cross-sections for threshold reactions.
- Effect of germanium crystal size on energy resolution, efficiency and peak shape of HPGe detectors.

## Analytical services

- Determination of nutrients and heavy metals in Nigerian food and beverages as well as bromine and iodine in medicinal herbs by epithermal NAA.
- Elemental analysis of flesh, bones and gills of popularly consumed fish in Nigeria to improve nutrition and health.
- Use of k0-epithermal NAA techniques for the determination of U, Th, K in archaeological materials.
- Geochemical and soil fertility mapping of Nigeria.
- Trace element abundances in Nigerian crude oils and lubricants.

# 3. Future Capabilities

The production of short and medium life radioisotopes is being investigated. A radiochemical laboratory will be established for this purpose. Other areas to be fully developed are:

- Study of the levels of toxic and heavy elements in wells, rivers, bottled and public water supplies, as well as monitoring of pollutants in air, water and sediments.
- Doping trace elements in ceramics and silicon wafers.
- Elemental analysis to examine evidence from crimes such as hair, nail and serum samples, and for the identification of the age of pottery and metal artefacts.

# 4. Contact Information

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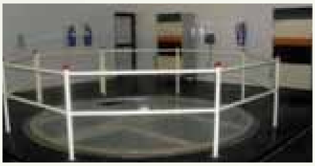
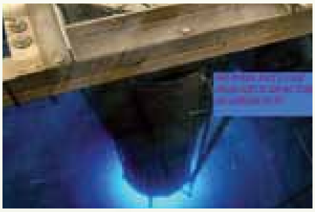
*NIRR-1 control console*



*NIRR-1 reactor top*



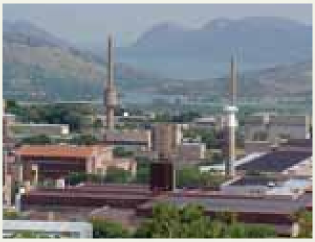
*NIRR-1 in operation*

*Sample preparation lab*

*Pneumatic sample transfer system*

*Counting room 2*

# SAFARI-1



*SAFARI-1 reactor site*

## 1. Technical Characteristics

Built in 1961 (initial criticality 1965), the first South African Fundamental Atomic Reactor Installation (SAFARI-1) is a pool type Materials Test Reactor (MTR) with a licensed operating power of 20 MW located at Pelindaba near Pretoria. The site is equipped with a full range of facilities and services supportive of nuclear technology development and production. SAFARI-1 has regularly demonstrated its success in the dual role of providing reliable services as a national asset to South Africa, while at the same time providing neutrons for the backbone of a very successful commercial enterprise.

### Technical features:

- Pool type research reactor of 20 MW power.
- Utilization focus on commercial applications.
- Since 2009 operates with a fully converted core with LEU fuel.
- Cooled and moderated by light water with a beryllium reflector.
- Twelve core irradiation facilities with maximum neutron flux $4 \times 10^{14}$ $cm^{-2}$ $s^{-1}$.
- Wide range of support facilities, including an MTR fuel manufacturing plant, extensive hot cell facilities, a radioisotope centre, a pipe storage facility for spent fuel, two disposal sites for low and medium level radioactive waste, and a radiochemistry laboratory.
- Reactor operates twenty four hours per day, seven days per week, with more than 300 days per year at full power.
- The SAFARI-1 Quality, Health, Safety, Environment (QHSE) management system is certified to ISO 9000 and ISO 14000, and is in the process of certification to OHSAS 18000.

## 2. Products and Services

### Irradiation

- Production of radioisotopes for medical application (both national level and for export) – Mo-99, I-131, etc.
- Neutron transmutation doping for silicon ingots widely used in the semiconductor industry.
- Pneumatic and fast pneumatic systems for NAA.
- Digital neutron radiography and tomography for various applications (oil and minerals exploration, civil engineering, archaeology and palaeoanthropology, nuclear waste research, etc.).

### Research and development

- Neutron diffraction for magnetic phase analysis, residual strain, chemical phase analysis, crystallography, magnetic phase analysis, nuclear materials research (potential users are industry and academia).
- Small angle neutron scattering for materials research.
- Utilization of beam ports for beam tube experiments, basic and applied research in physics and nuclear engineering.

### Education and training

- All training related to operation, management and applications of research reactors is conducted by a specially created Reactor Training Committee.

- Organization of national, regional and international training courses and workshops.
- Education and training for university students, including MSc and PhD projects.

Molybdenum-99 (Mo-99) produced in the research reactor naturally decays to technetium-99m (Tc-99m), which is described as a very elegant and reliable diagnostic agent. Tc-99m is used in four of every five diagnostic procedures worldwide (or 80% in overall nuclear medicine), an estimated 40 million procedures annually, for detection and staging of heart and cancer disease diagnoses. Currently, SAFARI-1 is one of the world's five largest producers of Mo-99. While the world demand for Mo-99 is growing, SAFARI-1 remains among the few reliable producers, participating in the supply chain of more than 50 countries worldwide including the USA, UK, Australia and the major European and Asian nations.

The efforts put into the management and training of reactor operations personnel has been shown to have a positive contribution to the efficient operation of SAFARI-1. Operator training is done in-house to a high standard. All theoretical examinations and practical tests have high pass requirements and all efforts of the trained students are supported financially. The unique shift structure allows continuous retraining as well as greater stability and flexibility and increased personnel economy.

## 3. Future Capabilities

Recent evaluations have indicated that an expected operational lifetime beyond 2020 would be quite realistic for the reactor. Through the past 45 years the reactor has been modernized several times. Still, the successful commercial use of the reactor allows constant development and improvement of facilities and infrastructure increasing utilization opportunities. Current developments include the following:

- SAFARI-1 has embarked on an ageing management programme to upgrade various reactor structures, systems and components in addition to other improvement projects over the next five years. This will enable an extension of its life up to 20 years to 2030.
- SANS facility for applications in nano-powders, polymers, textiles for nuclear waste and nuclear materials research for academia and industry.
- Neutron diffraction facility upgrades for residual stress and strain investigations for applied material research, including materials for future fission and fusion reactors.

## 4. Contact Information

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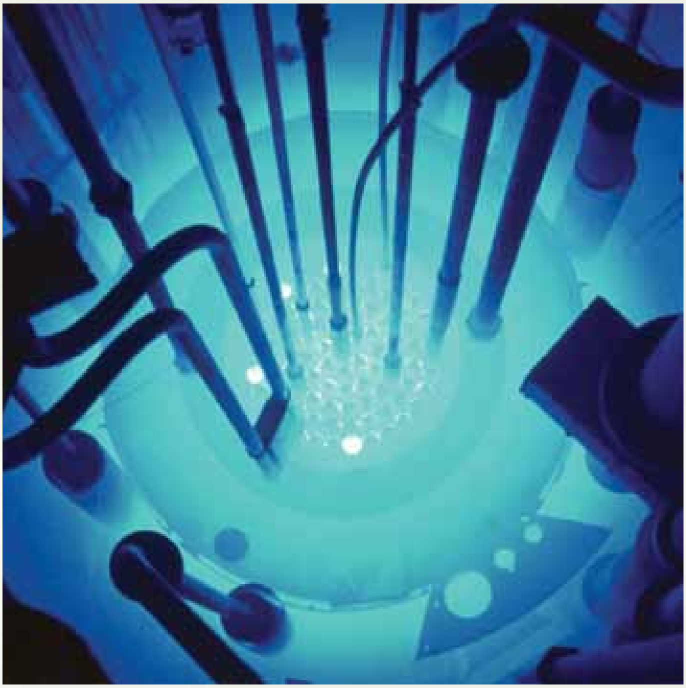
*Reactor core*

*Mo-99 produced at SAFARI-1 is used in radiation theraphy*

*Neutron radiography facility*

*Neutron tomography applied in palaeontology*

*Silicon ingot*



*Africa's newest RR, the MA-R1 of Morocco, will be featured during the technical tour at the 2011 International Conference on Research Reactors: Safe Management and Effective Utilization, 14-18 November, in Rabat*

Content provided in part by the research reactor member institutions of the African Regional Cooperative Agreement (AFRA)


November 2011

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