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General Performance and Utilization Plan of the Egyptian Second Research Reactor

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ABSTRACT

The Egyptian Second Research Reactor, ETRR-2, is a Multi-Purpose Reactor for material tests, radioisotopes production, neutron physics research, etc.. The reactor is an open pool type of 22 MW_{th} light water cooled and moderated, with an average flux of 2 x 10^{14} n/cm^2.s. Various experimental facilities are installed in the reactor to meet the requirements of the utilization group. Description of the reactor performance and proposed utilization plan is presented.

1. INTRODUCTION

The Egyptian Atomic Energy Authority of Egypt has since its establishment 40 years ago developed into holding the national leading role in the nuclear research and development. The first research reactor ETRR-1 commissioned in 1961, is one of the first reactors in the African content. The ETRR-1 is a 2 MW_{th} WWRS Russian type with maximum thermal flux in core of 2 x 10^{13} n/cm^2.s. The reactor was used for solid state, nuclear and reactor physics, studies for chemical research, for isotopes production and for biological irradiation. Although the reactor operation stopped for many times due to different reasons hundreds of papers and reports concerned works connected directly with the reactor were published. Due to the request of the Egyptian scientists in different fields and to meet the increasing demands of neutron users in addition to the continued development of the different neutron experimental technique there was a decision to have a new reactor ETRR-2 with better technical facilities.

The ETRR-2 project started in 1992, the reactor went critical for the first time on Nov. 1997 and reached its designed maximum power in Mar. 1998. The reactor now is under the stage of experimental facilities commissioning which scheduled to be finished by the end of 1998.

The ETRR-2 design objectives are oriented to meet the basic nuclear requirements taking into account the utilization group requirements. Design objectives of the ETRR-2 are:-

- Maximum unperturbed thermal flux at neutron trap should be at least 2 x 10^{14} n/Cm^2 Sec.
- Reactor Should be continuously operable at least for two weeks without refueling with about 2500

pcm excess reactivity for reactor control and for experiment.

- Power feed back reactivity coefficient should be negative.
- The average discharge burn up should be at least 50 % of the initial fissile material.
- Various experimental facilities and devices should be available.

The above mentioned design objectives were adapted by the Atomic Energy Authority (AEA) of Egypt in order to use the reactor for radioisotope production for medical and industrial purposes, basic and applied research in different disciplines (reactor and neutron physics, nuclear solid state, condensed matter, nuclear engineering, material / fuel tests and activation analysis) and for training the scientific and technical personnel.

2. REACTOR GENERAL DESCRIPTION

The reactor Main Pool (MP) is a cylindrical St. St. tank of 4.5 m diameter and 13.2 m height. A transference channel is connecting the MP with another Auxiliary Pool (AP) for the purpose of spent fuel elements storage and radioactive material handling. MP houses the core grid and its supporting structure, irradiation grid, cooling systems inlet and outlet pipes, neutron beam tubes, thermal column and core instrumentation. Figures 1 and 2 show reactor vertical and plan view respectively.

Core grid and its supporting structure

Core grid is a prismatic aluminum part, of 540*438*190 mm, with 30 squared lodging and two longitudinal slots which allow the assembly of the fuel elements and Control Plates (CP) guide box to configure the reactor core. Core grid is bolted to the core support structure which consists of two parts: a removable central part, and another part in contact with tank shell. Core is placed inside a square chimney which consists of two parts. Lower chimney is made of Zry-4 and bolted to the core supporting structure. On the other hand the upper chimney which is made of St. St. is connected to the lower one by a bolted joint and placed over the upper level of the fuel elements.

Cooling systems

Reactor core is cooled by upward forced circulation of light water. Outside the MP, the Core Cooling System (CCS) splits into two branches of 50% capacity each. Two flapper valves are installed at the highest points of the returning pipes of the CCS, one valve for each branch, to establish natural circulation circuit in case of absence of the forced circulation. The in-pool devices, reflectors, thermal column, and irradiation tubes , are cooled by downwards forced flow through the Pool Cooling System (PCS). In the case of absence of the forced circulation, provisions have been taken for natural circulation. There is a decay tank at the PCS circuit which allow the decay of N^{16}.

Reactivity Control Systems

ETRR-2 has two diverse independent reactivity control systems, First Shutdown System (FSS) and Second Shutdown System (SSS). The core control is accomplished through 6 Ag-In-Cd alloy absorbing plates with St. St. cladding. Absorbing plates dimensions are 144 mm width, 820 mm height and 3.6 mm thickness, and total thickness of 0.43 cm (with St. St. cladding). These plates move vertically inside guide boxes which are located parallel to the chimney. There are two guide boxes each one houses 3 CPs. Plates fully withdrawal position is at core's top. Movement of the six CPs to control the reactor power is achieved by 6 independent step motors attached to the hydraulic driving mechanisms located in a premise below the reactor pool. Fast shutdown is carried out by means of compressed air, injected from 6 independent tanks. If the FSS failed to the shutdown the reactor a gadolinium nitrate solution is injected to 4 independent chambers surrounded the core forming the lower chimney. The gadolinium nitrate solution is stored in 4 tanks under pressure of 7 bars and the chambers operates under 2.5 bars.

Fuel

Standard Fuel Element (FE) of the ETRR- 2 is MTR type of a square section 80*80 mm. Each FE has 19 Fuel Plates (FP), 17 inner plates and 2 outer plates. FP are separated from each other by 2.7 mm coolant channel. The 19 FPs are mechanically fixed to 2 side plates by a roll of swaging technique. The 2 side plates and the outer FPs are fixed to an end box by means of screws. The end box is a squared section piece with an internal centered hole of circular section to allow flow of coolant. In its lower end, it has 4 slotted parts, located over each of the corners to allow the insertion and griping of the FE clamp that holds the FE in the core grid. A handling pin connects the two side plates at the top position of the FE and it is fixed in stiff way by TIG welding.

FP meat is made by a fine and homogeneous dispersion of U_3O_8 particles with an enrichment of 19.75 % in weight of U^{235}, in a continuos matrix of pure commercially aluminum. FP active zone dimensions are 800 mm height, 640 mm width and 1.5 mm thickness. Cladding material is made of Al 6061 with thickness of 0.4 mm. Total mass of U^{235} in the standard FE is 404.7 g. Three types of FEs were used for the first core, *Standard, Reduced 1 and Reduced 2*. The three types of the FEs have the same specifications and the only difference between them is the contents of U^{235}. ETRR-2 first core FEs have been loaded as following:

- 7 FE of Standard type, 404.7 g. of U^{235}.
- 8 FE of Reduced 1 type, 148.2 g. of U^{235}.
- 17 FE of Reduced 2 type, 209 g. of U^{235}.

3. NUCLEAR PERFORMANCE DESIGN

MTR_PC2.6 /1/ system modules were used for cell and core calculations. WIMS was used in a slab geometrical model for ETRR-2 cell calculations. WIMS calculations were processed in different ways for obtaining the core constants for deferent materials and various distinct reactor segments /2/. HXS4.1 , macroscopic XS library manager, was used for the interface between cell and core calculations. Core calculations was performed using CITVAP 3.1 diffusion code, in x-y and x-y-z with an energy discretization of three groups. CITVAP 3.1 is a new version of CITATION II program.

Calculation systems was validated against measurements taken from different reactors: RA-2 and RA-6 at ARG. and NUR at Algeria. Additional validation against IAEA benchmark (IAEA TECDOC 233) have been , also, done.

The fuel management strategy that fulfills the requested conditions on power shape, excess of reactivity, and fuel burn up was obtained . First core has been chosen to be neutronically similar to the equilibrium core, reactivity feed back, prompt neutron life time, and effective delayed neutron fraction is not differ very much of the values for the equilibrium core /3/.

Table (I) presents the nuclear performance of the ETRR-2 equilibrium core. Power reactivity feed back coefficient is negative. Cycle length, average discharged burnup, and excess of reactivity are at the design basis. Poisons and power effects on excess of reactivity can be found. The Table shows the capabilities of the reactivity control systems. The reactor is still subcritical even if the most worth two control plates are fully extracted . The worth of the FSS is enough to shutdown the reactor and to suppress the reactivity increase due to temperature feed back and poisons decay, with enough Shutdown Margin (SM) , even in case of single failure. If the FSS failed, the SSS will be capable to shutdown the reactor even in case of single failure, with the CPs compensating the excess of reactivity.

Table (I) ETRR-2 Equilibrium Core Nuclear Performance.

Power (MW_{th})	***22***
Fuel Loading (Kg U^{235})	11.74
Core Cycle Length (FPds)	***19***
Power Coefficient (pcm / MW)	***-5***
Excess Reactivity (pcm)	
• ***Cold w/o Xe***	*8250*
• *Hot with Xe*	*4430*
• *EOC hot with Xe*	*2510*
Shutdown System Capabilities (pcm)	
• *All CPs*	13350
• *(5 out of 6) CPs*	9920
• *(4 out of 6) CPs*	9790
• *SSS*	6600
• *SSS (3out of 4)*	4470
Shutdown Margin (SM)	
• *FSS*	5100
• *FSS (5 out of 6)*	1620
• *SSS*	2810
• *SSS (3 out of 4)*	650
Average Discharge burnup (%)	***62.22***
prompt Neutron Lifetime (μ Sec)	*75*
Effective β (pcm)	***720***

4. UTILIZATION PLAN

(i) Fuel and Material Test

There are 26 irradiation positions at the ETRR-2 irradiation grid. Here, the neutron flux is suitable to the material and fuel irradiation for R&D. Six positions out of those 26 are core adjacent. One of those 6 positions is dedicated for a high pressure and temperature test rig of 20 KWatt power. Another high pressure and temperature

test loop of 500 KW_{th} power which can be moved by a dedicated mechanism far or close to the reactor core will be installed. The loop is capable of producing chemical and thermalhydraulic environment identical to those expected in power reactors. Slightly enriched CANDU fuel bundle can be irradiated at this loop. Loop inner diameter is 10.3 cm and its active height is 50 cm. At the rig a CANDU fuel rod can be irradiated. Rig inner diameter is 1.3 cm and its active height is 40 cm.
The loop and the rig will be available before the end of 1998. The following experiments and tests can be conducted :

- Engineering tests on full or partial size fuel bundle.
- Technological investigation in coolant chemical and thermalhydrulics conditions: fuel cladding waterside corrosion, heat transfer mechanisms study.
- Studies on defective fuel behavior and safety related experiments. Measurements of dimensional changes and centerline temperature in pellet.
- Analyses of the fission product releases.
- Study of pellet-cladding interaction.
- Investigations on the effect of high burnup on Uranium oxide fuel thermal conductivity.

In addition, material test to investigate mechanical properties can, also, be conducted at the ETRR-2. ETRR-2 is equipped with a concrete hot Testing Cell, which is helpful in carrying out destructive and non-destructive tests on materials and on highly burned spent fuel. Testing cell is connected to the AP by means of conduct provided with a sample holding cart and is equipped with material testing devices so that impact, elongation and compact tension, creep analyses, and microhardening tests on irradiated samples can be conducted.

(ii) Radioisotope Production

Radioisotopes have a wide range of applications in medical and industrial fields. In Egypt, short-lived isotopes will be produced by a 25 Mev Cyclotron which is still under construction. In ETRR-2, the core central position is dedicated to Co^{60} production, 50 KCi can be produced annually. Co^{60} sources are processed and calibrated at a concrete Cobalt hot Cell located at the reactor building. The Cobalt Cell is capable for manipulating and processing up to 10 KCi sources. At the irradiation grid positions, several radioisotopes can be produced such as Ir^{192} and Tc^{99m} . In addition to those radioisotopes that will be produced at the Cyclotron, those irradiation grid positions can be conducted to produce several radioisotopes such as I^{125} , I^{131}, C^{14} , P^{32} , Cr^{51} , Fe^{54} , and Mo^{99} . Samples for radioisotopes production will be irradiated in a specially designed Irradiation Boxes (IB) made of aluminum. The radiation-induced heat in the IBs is removed by PCS.

A Transference Cell is located at the MP edge, the movement of irradiated samples, as well as samples to be irradiated is conducted. Irradiation capsules are conducted from the transference cell to a lead shielded universal or loading cell, as appropriate. transference cell is connected to the MP by means of a conduct which has been provided with a sample holding cart. At the universal cell the irradiated capsules are received, opened, and their contents are fractioned. Chemical process with radioactive material are also developed at the universal cell. At the loading cell the irradiated capsules are received and shielded for their manipulation and transportation.

(iii) Boron Neutron Capture Therapy (BNCT)

One of the promising features of ETRR-2 facilities is the BNCT facility. The facility will be the first in Africa and will cover a population of 600 million people. A radial beam tube starting at the thermal column middle position and tumor irradiation room located aligned with it are dedicated to serve this purpose. It is planned to use epithermal neutron beam. The goal of which is to generate a neutron beam with enough intensity to provide therapy while minimizing patient risk and discomfort. The beam should have minimal contamination from fast neutrons, gamma, and thermal neutron components. The fulfillment of these requirements need the design of many different devices (cavities, neutron converters, attenuators, filters, and collimators) for the fine tuning of the resulting spectra. The above mentioned devices are under design stage. However, the facility will be made available before the mid of 1999.

(iv) Semiconductor Production

ETRR-2 thermal column is provided with three large holes, two of them will be used for semiconductor production by NTD. No interface with BNCT facility is produced by the NTD facility. Flux variation at the two holes region during the operation is relatively small and fast to thermal flux ratio is lower than 0.1. Initial resistivity of Si is about 1000 Ohm.cm . However, the final resistively is about 30 Ohm.cm. Maximum acceptable deviation of the fluence through the sample is 5%. Si processing lab. located at the reactor building. Rig diameter is 12 cm and with length of 28 cm so that approximately 4.3 Tons of semiconductor can be produced annually.

(v) Neutron Activation Analyses (NAA)

Many irradiation positions at the irradiation grid will be used for NAA. The third hole at the thermal column will be used too. There are two pneumatic transport systems enabling fast and safe transference of the capsules between the NAA holes and the end station at a chemical hoods at a hot lab. Irradiation capsules can be transferred manually through the Transference Cell cartage to the MP and then to the NAA holes at the irradiation grid. Irradiation capsules are sent to NAA lab to be analyzed. Environmental analyses, geological ores, biomedical and criminal studies will be carried out at the NAA lab.

(vi) Neutron Beam Experiments

In addition to the radial beam tube used for BNCT, the ETRR-2 is equipped with 4 beam tubes: 2 radial tubes, one tangential tube with two ports, and an under water radial tube housed in the reactor tank. A neutron radiography room equipped with neutron radiography facility is located at the end of one of the radial beam tubes. While the under water radial tube will be used for under water neutron radiography for highly activated samples.

On the other hand a neutron tomography scanner system is installed in front of the second radial tube. Five neutron scattering instruments are recommended to be installed, which are considered most useful for present prospective research fields as well as appropriate to the MPR characteristics. One instrument, the High Resolution Powder Diffractometer (HPRD) will be installed in the reactor hall in front of one port of the tangential tube and looking at a thermal beryllium source. A cold neutron guide hall is also built and decision has been already taken to install a cold neutron source on the opposite opening of the through tangential tube, based on liquid hydrogen, on account of its great capability supply a copious flux of long wave length neutron. The other four instruments will be installed in the neutron house, using the cold neutron beams transported by the guides are :-

- Small Angel Neutron Spectrometer (SANS)
- Triple Axes Spectrometer (TAS) with polarization analysis.
- Reflectometer for liquid and solid state samples.
- Prompt Gamma Analysis (PGA)

5. CONCLUSIONS

- ETRR-2 can be utilized for fuel/material tests, radioisotope and semiconductors production, BNCT, NAA, neutron radiography, and neutron beam experiments.
- Various experimental devices and irradiation facilities are provided and high thermal flux is available so that meaningful results during experiments can be obtained.
- Nuclear design performance and commissioning test results showed that the reactor can be safely operated.
- Reactor can be continuously operated at full power for 19 days without refueling with 2510 pcm excess of reactivity.
- The reactor will play an important role in R&D program in Egypt as soon as its experimental facilities is commissioned.

6. REFERENCES

/1/ INVAP SE, MTR_PC2.6 User's Manual. ARG., 1995.

/2/ Sandra Matzekin, Update of Data for Neutronic Calculation Line. 0767 0740 3TANU 132 2B. INVAP SE, 1997.

/3/ INVAP SE, Safety Analysis Report of the MPR Reactor. 0767 5325 3IBLI 001 1O. ARG., 1997.

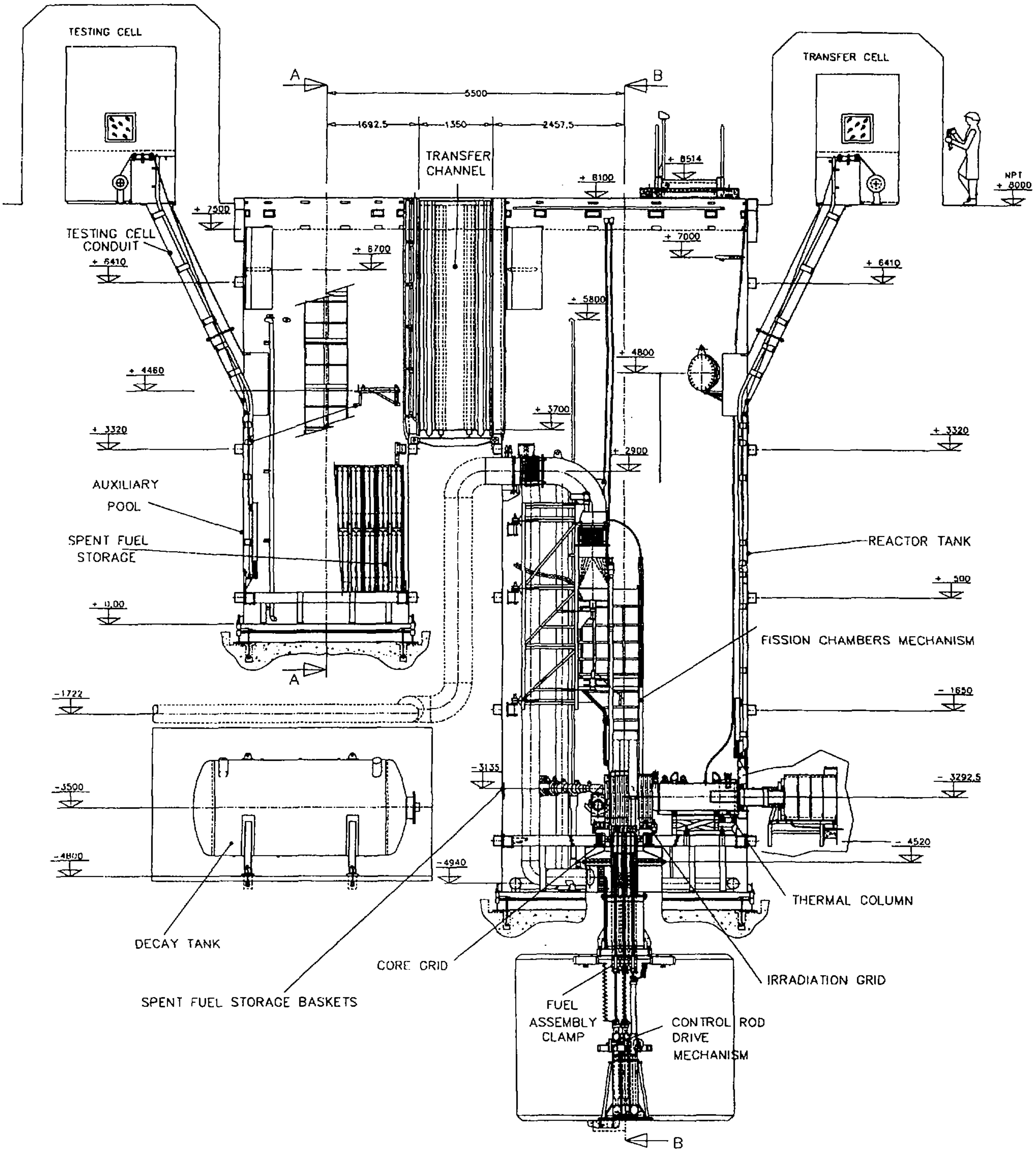

Figure 1. Reactor Vertical View.

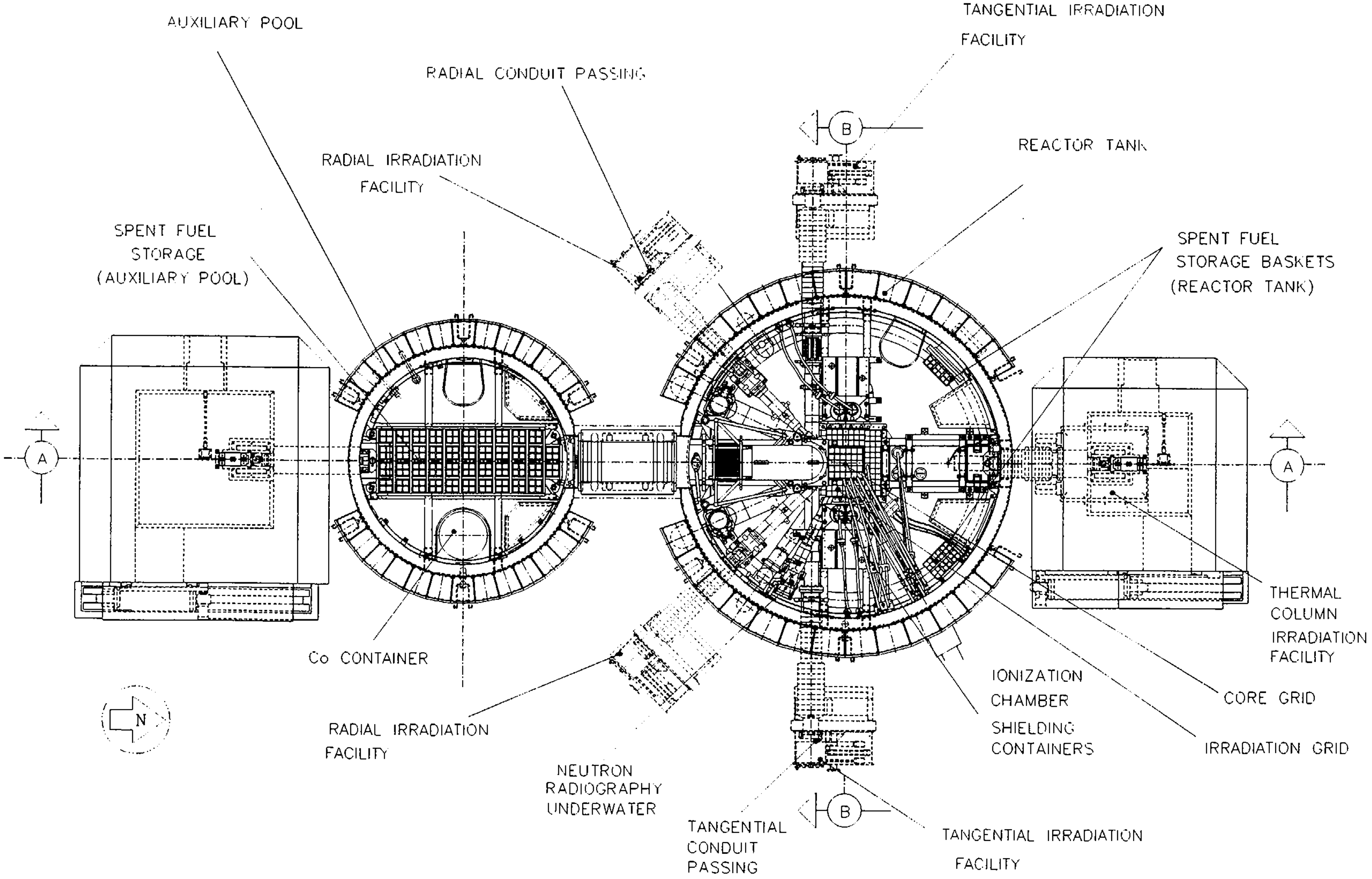

Figure 2. Reactor Plan View.