18th International Conference on Structural Mechanics in Reactor Technology (SMiRT 18)
Beijing, China, August 7-12, 2005
SMiRT18-C07-5

HOW THE RRR NEUTRONIC CHARACTERISTICS IMPACT ON THE MECHANICAL DESIGN

Eduardo Villarino
INVAP S.E.
Moreno 1089, Bariloche, Argentina
Phone: (54)(2944) 445436,
Fax: (54)(2944) 423053
E-mail: men@invap.com.ar

Kurt Coquibus
INVAP S.E.
Moreno 1089, Bariloche, Argentina
Phone: (54)(2944) 445436,
Fax: (54)(2944) 423053
E-mail: coquibus@invap.com.ar

ABSTRACT

This paper describes how the neutronic characteristics of a very demanding research reactor facility impact on the mechanical design of the reactor core. The Replacement Research Reactor (RRR) for the Australian Nuclear Science and Technology Organization is described making emphasis in the mechanical solutions to improve the core performance. The compact core is located inside a chimney, surrounded by heavy water contained in the Reflector Vessel. The whole assembly is at the bottom of the Reactor Pool, which is full of de-mineralized light water acting as coolant and moderator and biological shielding.

The core is an array of sixteen plate-type Fuel Assemblies (FAs) and five absorber plates, which are called Control Plates (CP). The coolant is light water, which flows upwards.

The final design of the core layout and control guide boxes was adopted to minimize the flux and PPF perturbation during the normal operation. The four lateral control plates are used mainly to shutdown the reactor and to compensate large reactivity transients. The central and cruciform regulating plate is used to compensate the reactivity change during the cycle operation. The regulating plate does minimize perturbation on PPF and irradiation fluxes.

The design of the reflector tank fulfills all the flux requirements for the irradiation facilities and also the flux perturbation between irradiation facilities.

Keywords: Neutronic, Research Reactor, Mechanical Design.

FACILITY DESCRIPTION

The RRR Facility is a multi-purpose open-pool type reactor. The nominal fission power of the reactor is 20 MW. The compact core is located inside a chimney, surrounded by heavy water contained in the Reflector Vessel. The whole assembly is at the bottom of the Reactor Pool, which is full of de-mineralized light water acting as coolant and moderator and biological shielding.

The core is an array of sixteen plate-type Fuel Assemblies (FAs) and five absorber plates, which are called Control Plates. The FAs are square shaped, within each FA there are twenty one fuel plates and it uses Cadmium wires as burnable poison. The coolant is light water, which flows upwards.

Reactor shut down can be achieved by two independent means, which are the insertion of five CPs into the core, or the partial drainage of the heavy water from the Reflector Vessel.

The fuel plates consist of meat and cladding. Two types of meat are considered: uranium silicide powder or uranium molybdenum powder, both dispersed in an aluminum matrix and with enrichment lower than 20%.

The reactor will be provided with advanced cold and thermal neutron sources to produce neutrons in specific spectral ranges. Specially designed neutron beam guides featuring high technology super-mirrors will extract these neutrons from their sources. One of the main purposes of the reactor includes the large-scale production and processing of radionuclides. The following facilities are specified:

- Bulk production irradiation facilities, to irradiate targets contained in rigs that are placed inside irradiation tubes provided in the reflector tank.
- Long residence time general-purpose irradiation facilities, to irradiate targets contained in sealed cans. The cans are sent for irradiation to irradiation rigs at the reflector tank by means of a pneumatic transport system.
- Short residence time facility, to carry out Neutron Activation Analysis.
- Large volume irradiation facilities, for neutron transmutation doping of single-crystal silicon ingots and for bulk irradiation of ore samples for neutron activation analysis.

The conceptual mechanical characteristics of the reactor core were designed during the preparation of the offer.

Different concepts were adopted to fulfill the tender requirements, for example:

1) Large volume of high performance irradiation facilities:
   - D2O Reflector which requires a reflector tank, and a chimney surrounding the reactor core.
   - Compact core (16 FA, 35x35x61.5cm3)
   - High Density Fuel material.
   - Square chimney
   - Fins on the chimney faces to reduce structural materials.
   - Burnable Poisons to reduce volume of control plates materials

2) Safe operation of the facility:
   - Two shutdown systems.
   - The first shutdown system will be an automatic fast-acting system capable of shutting the reactor down for all relevant design-basis fault sequences (5 Control Plates).
   - The second reactor shutdown system will be automatic and independent of the first, using a different means of operation than that used for the first reactor shutdown system, partial dumping the heavy water reflector. The fast actuation of this system makes a strong requirement for the structural behavior of the reflector tank.
   - A central regulating rod to minimize Power Peaking Factor perturbations.

3) Very low flux perturbation along the operation cycle of the reactor core (normal operation and irradiation facilities movement)
   - A central regulating rod to minimize flux perturbation
   - Layout of the Compensating rod. Cruciform shape
   - Layout of the irradiation facilities.

NUCLEAR SAFETY

The neutronic design of the RRR is guided by a set of neutronic design criteria. These criteria include the contractual requirements and the nuclear safety requirements. This section gives a summary of the nuclear safety neutronic design criteria

Reactivity Design Criteria.

Different criteria were settled for the core design, like negative feedback coefficients, enough shutdown margins for both shutdown systems, including single failure criteria. Actuation time of the shutdown systems (measure as shutdown margin vs. time), reactivity worth of the irradiation facility, reactivity rate of the irradiation facilities, reactivity rate of the control system, etc.

Thermalhydraulic related criteria

For 20 MWTh, the number of FAs shall be 16 and the power peaking factor lower than 3.

Operating Condition Design Bases.

A minimum end of cycle reactivity to allow the reactor to return to full power operation 30 minutes after a reactor trip occurs and the cycle length must be at least 28 days, with two days for reshuffling and maintenance.

NEUTRONIC REQUIREMENTS

The contract specifies several neutronic aspects to be fulfilled by the core design and to be verified during the commissioning tests. The following list gives a summary of such warranted values:

Flux level.

Several irradiation facilities require a minimum value for the neutron flux; but there are other irradiation facilities requiring a minimum and maximum neutron flux value.

Spectra

There are requirements on the flux value for different energy of neutrons

- Cold neutron flux: neutrons with energy lower than 10 meV.
- Thermal neutron flux: there are two different definitions:
- Neutron sources: neutrons with energy lower than 100 meV and greater than 10 meV.
- Radioisotope production: neutrons with energy lower than 0.6 eV.
- Fast neutron flux: neutrons with energy greater than 1 MeV.

There is an additional requirement to keep room for a future hot neutron source. The hot neutron flux is defined for neutrons with energy lower than 1 eV and greater than 100 meV. In the case of the neutron beams (cold and thermal) there is also a requirement on energy of the spectrum peak

Homogeneity

There are requirements on the flux homogeneity on the different irradiation facilities, for example the axial homogeneity on NTD facilities, inside an irradiation can, and within several targets of the same flux level.

Perturbation.

There are requirements on the flux perturbation due to the movement of the irradiation samples. It means the flux in the other facilities must not change a given value when an irradiation device is moved.

There is also a requirement on the irradiation facilities flux perturbation during normal operation.

Burnup.

A minimum discharge burnup is required.

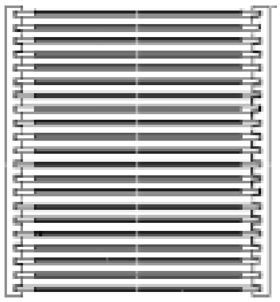
Restart capability.

The reactor must have the capability to return to full power operation after a trip, within 30 minutes. This condition is not only a neutronic requirement, but it also requires an important excess of reactivity at EOC to have enough time to return the reactor at full power.

CORE DESIGN

A compact core with 16 FA has been designed to fulfill all the neutronic design criteria.

Two types of FA can be used: U_3Si_2 with an Uranium density of 4.8 g-U/cm^3, and a U-9%Mo with an Uranium density of 7.0 g-U/cm^3. The fuel management strategy have an operating cycle of 33 FPD and 2 days for maintenance, and the number of fresh FA added per cycle is 3 for U_3Si_2 and 2 for U-Mo.



Five control plates are needed to control and shutdown the reactor. The regulating plate layout (central rod) minimizes the flux perturbation on the irradiation facilities and on the power peaking factor. The usage of burnable poison and the size of the regulating rod fulfill a design basis to control the operating cycle with only the regulating rod.

The Fig. 1 shows a scheme of the core layout with the FA and the control plates.

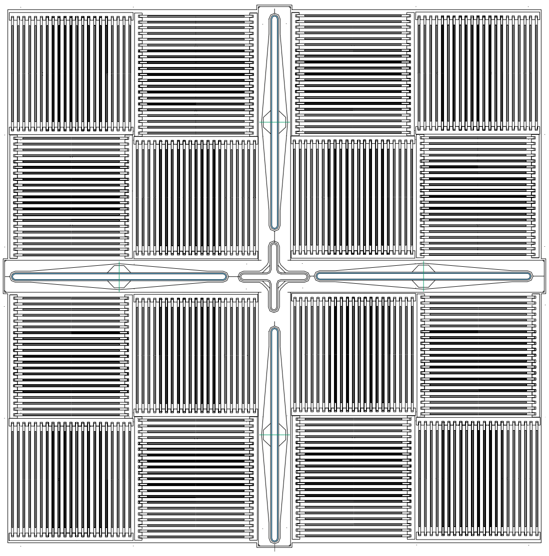


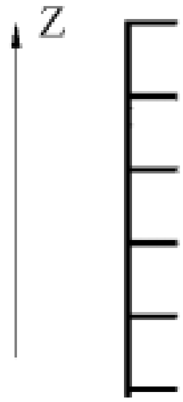
Figure. 1. Core layout scheme.

This figure 1 summarizes all the mechanical design goals needed to fulfill the very demanding neutronic requirements. The following subsections describe how the neutronic requirements were taken into account in each component of the core.

<u>Square zircaloy chimney.</u>

A square mechanical design of the chimney was finally decided for the following neutronic aspects:

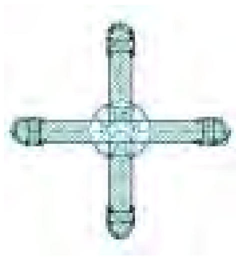
- Utilization of very well qualified square shaped Fuel Assembly. This is not only a requirement for the already qualified U_3Si_2 fuel type, but also for the under development U-Mo fuel type.
- A compact core design, to improve flux to power ratio.
- Minimize thermal neutron flux lost in the heavy water reflector, avoiding the usage of solid reflectors.
- Make easier the cross-shaped control plate layout. To minimize the flux perturbation during normal operation.
- The thickness of the zircaloy wall was minimized using fins to preserver the structural requirements (see scheme). A special design of the chimney corner was also done.



<u>Control Plate layout.</u>

The layout of the 5 control plates was designed to take into account the following neutronic requirements.

- minimize the power peaking factor perturbation during reactor operation on a very compact core design
- Minimize the flux perturbation on the irradiation facilities during normal operation.
- 4 control plates will be used for compensating large reactivity transients and shutdown the reactor.
- 1 central regulating plate (see scheme) to control the burn-up reactivity change along the cycle length.



Fuel Assembly layout.

The layout of the fuel Assemblies is designed to improve the coolant capabilities of the structural materials like chimney and control guide plates, its also improve the layout of burnable poison minimizing the flux perturbation on the Cold and thermal neutrons sources.

REFLECTOR TANK DESIGN

The layout of the irradiation facilities is shown the Fig. 2. Their position was optimized maximizing the margins to fulfill the flux requirement and the flux perturbation between them.

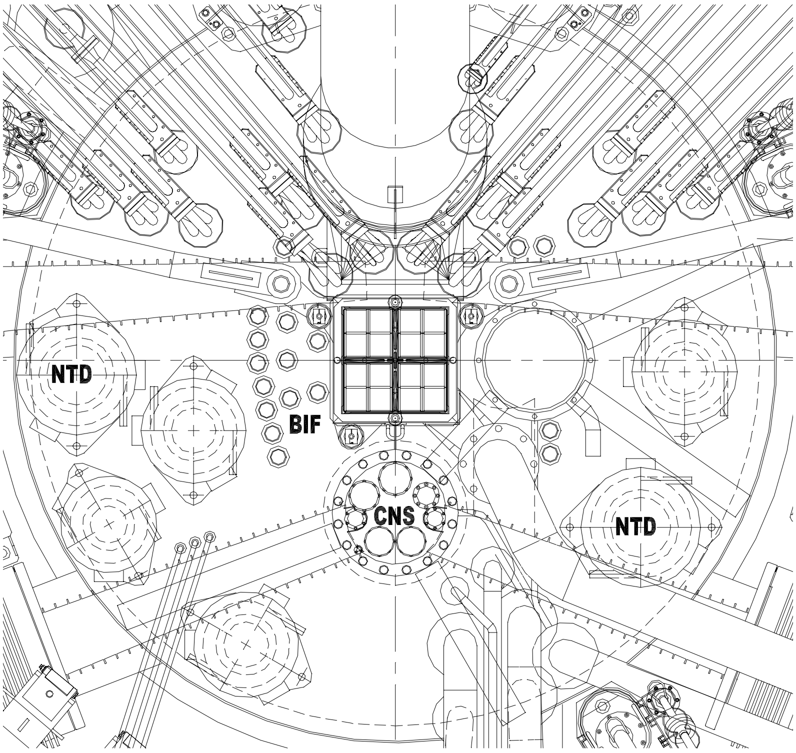


Figure 2. Upper View of the Reflector Tank and main Irradiation Facilities.

The huge volume of irradiation facilities with high thermal neutron flux requires the usage of heavy water reflector. A reflector tank is needed to house all the irradiation facilities like radioisotope production, Silicon doping and cold and thermal neutron sources and its associated beams.

The layout of the irradiation facility was done conceptually dividing the reflector tank in four areas.

Cold Neutron Source.

The flux requirement on the cold neutron source and its perturbation requirement during normal operation make that one face of the reactor core is needed only for this source. This source has also two different beams.

The design of the cold neutron beam is very demanding with respect to the water gaps between the beams and the cold source.

Thermal Neutron source.

The flux requirement on the thermal neutron source and its perturbation requirement during normal operation make that one face of the reactor core is needed only for this source. This source has also two different beams. The axial location of this source allows the location of some pneumatic facilities in the upper part of the reflector tank.

Hot Neutron source.

A room for a future hot neutron source is needed in the present design of the reflector tank. The volume needed for this type of source requires one face of the reactor core. This source has only one beam, which it is located at different level of the Cold neutron source beam.

Bulk irradiation facilities.

The remaining face of the reactor core was conceptually used for the location of the bulk radioisotope production facilities.

These 17 high volume irradiation facilities have some flux and flux perturbation requirement that only twelve of them were possible to locate in a face of the reactor core. The other 5 were located close to the Hot neutron source and close to the pneumatic facilities.

This facilities have an additional requirement: To have direct access to the facility from the open pool, to allow an easy maneuvering from the reactor operating bridge.

Pneumatic irradiation facility.

Several facilities were located were no direct access from the open pool is required. Due to the different flux level requirements were possible to spread in the reflector tank. The facilities with higher flux requirement were located close to the thermal neutron source, but in the upper part of the core, minimizing the flux perturbation on the thermal neutron source of the pneumatic facilities.

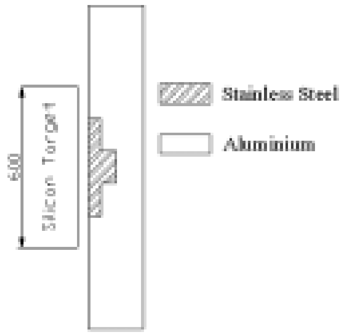
These facilities have neutron flux and temperature detectors.

Silicon doping facilities.

This very high volume facility with a very demanding flux profile has a relative low flux requirement. This allows locating on the border of the reflector tank.

A very special component in this facility is the removable flux flattener. This component (see scheme) is designed to allow a very flat axial profile on the whole active zone of the silicon to be irradiated. The requirement is to have a 3% of non-uniformity on the thermal flux axial profile.

These facilities have neutron flux detectors.



CONCLUSIONS

The final design of the reactor core, and reflector tank are very important to fulfill the neutronic requirements of the very high performance multipurpose facility, like the RRR research reactor.

The operational conditions of both components with the additional neutronic, thermal-hydraulic, seismic, structural and material requirements make a very complex and multidisciplinary design. Different review meetings to optimize the overall design were carried out during the tender preparation, preliminary design and detail design stages.

From neutronic point of view, the final design of the core layout and control guide boxes was adopted to minimize the flux and PPF perturbation during the normal operation.

The four lateral control plates are used mainly to shutdown the reactor and to compensate large reactivity transients. The central and cruciform regulating plate is used to compensate the reactivity change during the operation cycle. The regulating plate does minimize perturbation on PPF and irradiation fluxes. The usage of burnable poisons reduces the volume of controls plate materials.

The main reason to adopt the FA layout is to improve the cooling of the non-active structural materials, like control guide boxes and the inner wall of the chimney.

The reflector tank house several irradiation facilities with a huge volume of high-level thermal neutron flux. Different type of irradiation facilities was located with different neutron spectra requirements and flux levels. One important aspect of the present design is the minimization of the flux perturbation during the normal operation of the reactor.

The present design of both components fulfills all the neutronic requirements.