NEUTRONIC CHARACTERISTICS OF THE RRR

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ABSTRACT

This paper describes the general neutronic characteristics of the Replacement Research Reactor (RRR) for the Australian Nuclear Science and Technology Organisation (ANSTO).

The RRR Facility is a multi-purpose open-pool type reactor. The nominal fission power of the reactor is 20 MW. The 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 description covers different aspect of the neutronic design: fuel assemblies (FA) characteristics, irradiation facilities, requirements, operational requirements, etc.

An important neutronic characteristic of the RRR design is that it handles two types of FA, the well-known and qualified U_3Si_2 fuel type and the under qualification process U-Mo FA type.

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

Several irradiation facilities are located around the reactor core. Three types of neutron sources: a cold neutron source with two tangential beams and several neutron guides, a thermal neutron source with two beams and several neutron guides, and a room reserved for a future hot neutron source with a beam. The core has also 17 vertical irradiation tubes with 5 targets each for bulk radioisotope production (for example: Ir, Mo and I), 19 pneumatic rigs with 57 target positions for different purposes: radioisotope production, neutron activation analysis (NAA). Finally it has 6 neutron transmutation doping (NTD) facilities. A general description and main characteristics of the present core design is also given.

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RRR GENERAL DESCRIPTION

The RRR Facility is a multi-purpose open-pool type reactor. The nominal fission power of the reactor is 20 MW. The 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 FAs are square shaped, each of them containing 21 fuel plates and using Cd 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 CRs 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 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 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 following sections will describe general aspects of the neutronic design of RRR, its neutronic nuclear safety characteristic and its neutronic requirements.

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 or beams: 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.

DESIGN CALCULATION CODES

Figure 1 shows the design flowchart, which covers all the neutronic design aspects. It shows how the neutronic design is guided by the following topics:

- ✓ Neutronic design criteria
- ✓ Documented calculation model and data.
- ✓ Usage of validated calculation codes
- ✓ The usage of experimental measurements to verify a proposed design, etc.

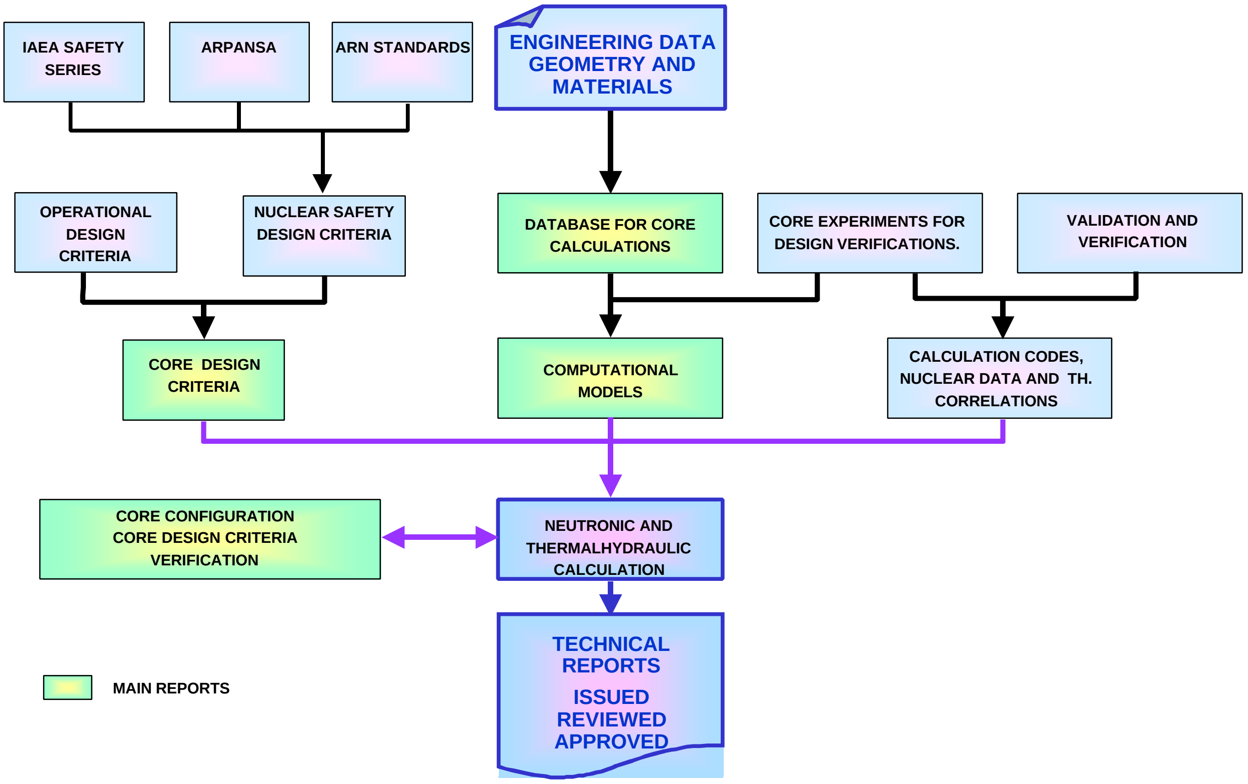

Figure 1. Neutronic Design Flow Chart

The calculation of the RRR is done in several steps and using different validated codes. These steps and codes are summarized in a calculation line. The calculation line for RRR is divided in three different methodologies:
Calculation using Macroscopic cross sections. This methodology is used for almost all the neutronic parameters. The equilibrium core burnup distribution is the most important calculated parameter.

Calculation using Microscopic cross sections. This methodology is used for the calculation of the kinetic parameters and time dependent calculation.

Montecarlo code. This calculation methodology is used for the verification of several neutronic parameters.

The first two methodologies are divided in 3 steps:
- ✓ Library generation
- ✓ Cell calculation
- ✓ Core calculation

The last methodology is divided in 2 steps:
- ✓ Library generation
- ✓ Montecarlo calculation

These methodologies and their interfaces are shown in Fig. 2. It shows several codes and a short description of the most relevant items is given.

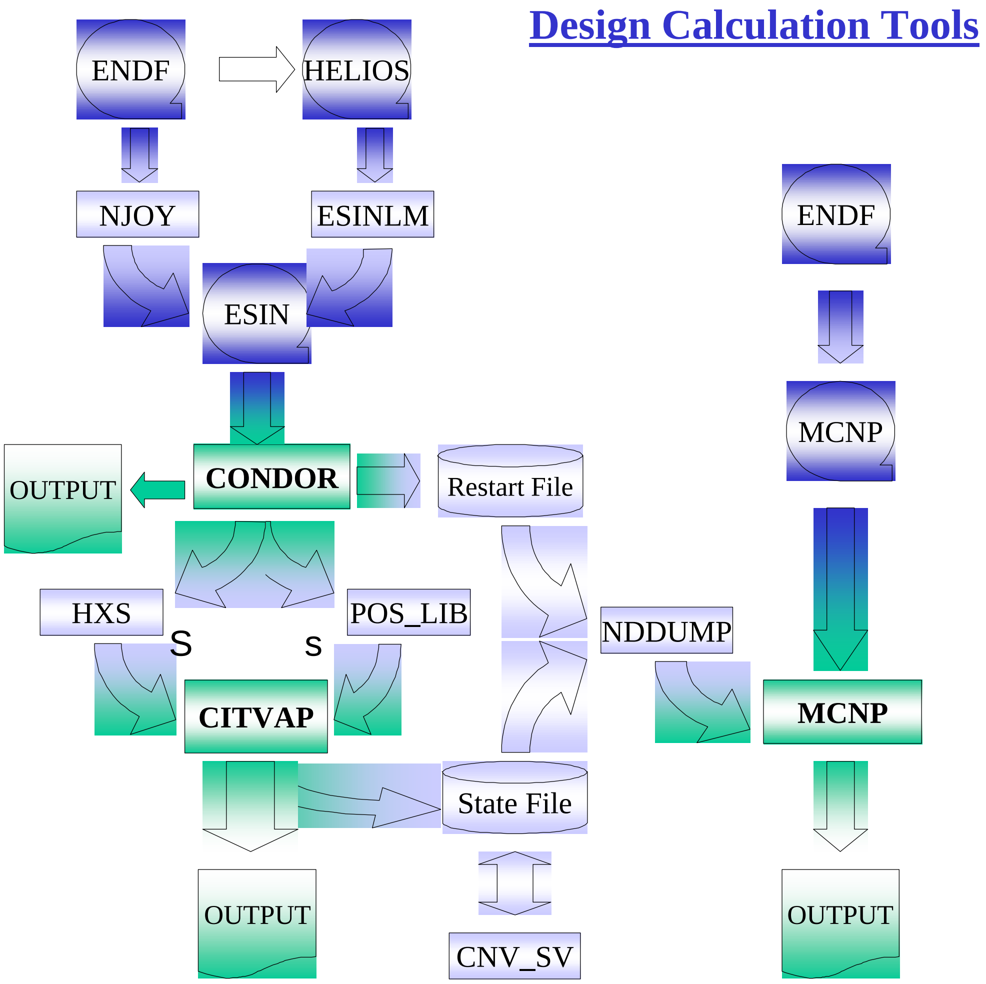

Figure 2. Calculation Line Scheme

Nuclear Data Library. Two different primary data are used to generate ESIN type libraries.

WIMS-ESIN. This results from the 69 groups WIMS library, which has good thermal detail as well as resonant parameters. Moreover, it has isotopes added from the ENDF/B-IV library for control absorber material definition and a new set of isotopes was added from the ENDF/B-VI: Ir and Te, using NJOY system.

HELIOS-ESIN. Primary data of the HELIOS are from the ENDF/B-VI library. The library has three different group structures: 190, 89 and 34 groups.

CONDOR. The CONDOR Code for neutron calculations is used to calculate fuel cells, fuel-rod clusters, as well as fuel plates with slab geometry or 2D geometry. Flux distribution within the region to be calculated is obtained through the collision probability method or the Heterogeneous Response Method in a multi-group scheme with various types of boundary conditions.

HXS. The HXS program (Cross section handler) represents a major utility. It handles macroscopic cross-sections (identified by a name) in library form.

CITVAP. The CITVAP reactor calculation code is a new version of the CITATION-II code, developed by INVAP's Nuclear Engineering Division. The code was developed to improve CITATION-II performance. In addition, programming modifications were performed for its implementation on personal computers. The code solves 1, 2 or 3-dimensional multi-group diffusion equations in rectangular or cylindrical geometry. Spatial discretization can also be achieved with triangular or hexagonal meshes. Nuclear data can be provided as microscopic or macroscopic cross section libraries.

MCNP Montecarlo Code. This well-known Montecarlo transport code for neutron and gamma calculations uses ENDF/B-VI cross Sections in any order and performs 3-D calculations. It is used to verify some neutron parameters through an independent calculation method.

PRESENT DESIGN

General aspect. A compact core with 16 FA has been designed to fulfill all the neutronic design criteria. The Fig. 3 shows a scheme of the core layout with the FA and the control rods.

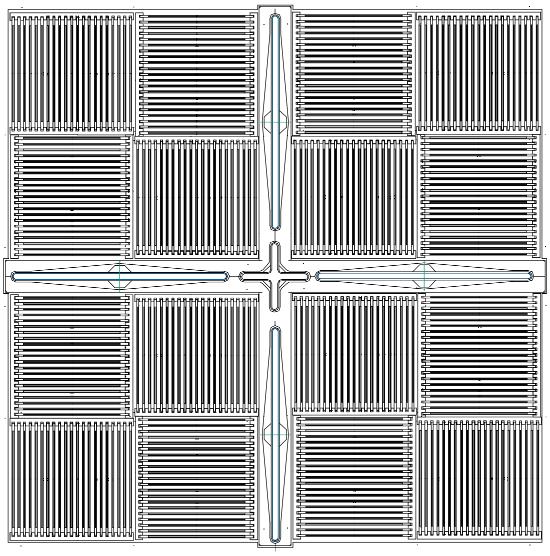

Figure. 3. Core layout scheme.

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 FA 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 layout of the irradiation facilities is shown the Fig. 4. Their position was optimized maximizing the margins to fulfill the flux requirement and the flux perturbation between them.

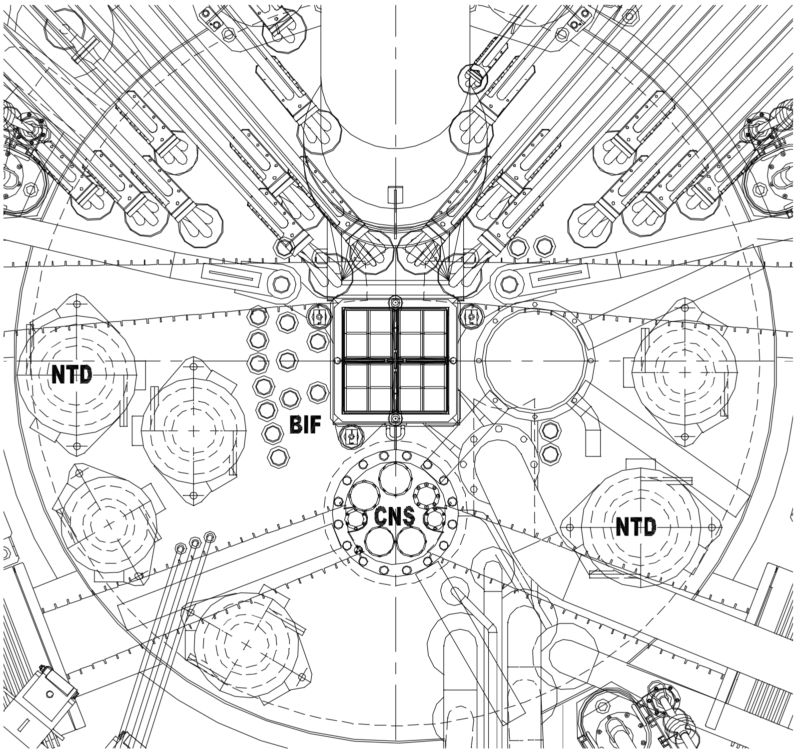

Figure 4. Upper View of the Reflector Tank and main Irradiation Facilities.

Table 1 summarizes the main equilibrium core reactivities (in pcm) for a simplified fuel managamente strategy, for both types of FA.

TABLE 1. Core Reactivities

	U_3Si_2		U-Mo	
State	BOC	EOC	BOC	EOC
Full power	3990	1200	4230	2290
Hot. No Xenon	7700	4980	8065	6195
Cold. No Xenon	8015	5315	8370	6500

Table 2 shows a conceptual verification of the most important design criteria verification.

TABLE 2. Summary Design criteria verification

Design Criteria	Limit	U_3Si_2	U-Mo
First Shutdown System (FSS) Shutdown margin (SM)	≥ 3000 pcm	8410	6300
First Shutdown System: SM with single failure.	≥ 1000 pcm	3745	2090
Second Shutdown System (SSS) Shutdown margin.	≥ 1000 pcm	3575	3580
Power Peaking factor	= 3.0	2.30	2.36
End of Cycle reactivity	≥ 1000 pcm	1200	2290
Actuation of FSS at 0.5 sec	≥ 2000 pcm	8500	6490
Actuation of SSS At 15 sec.	≥ 3000 pcm	6010	6010

Flux irradiation facilities fluxes. This subsection gives neutronic fluxes per irradiation facility type. The values presented are for the BOC state of the U_3Si_2 FA type.

Bulk Production irradiation Facilities. These facilities have 17 irradiation tubes with 5 targets each. Table 5 shows the maximum and minimum thermal flux per target and the average value for all the targets.

TABLE 5. Bulk production irradiation facility fluxes

Very High Flux Facilities (2 tubes)	
Minimum	1.6E+14
Maximum	3.2E+14
Average	2.3E+14
High Flux Facilities (3 tubes)	
Minimum	1.1E+14
Maximum	1.9E+14
Average	1.4E+14
Medium Flux Facilities (12 tubes)	
Minimum	6.2E+13
Maximum	1.3E+14
Average	8.8E+13

Pneumatic Conveyor Flux Facilities. These facilities have 19 irradiation rigs with a different number of targets per facility (it ranges from 1 to 5 targets per rig). Table 6 shows the thermal flux (except FF: fast flux facility) for each level of flux requirement. It shows the maximum and minimum per rig

TABLE 6. Pneumatic irradiation facility fluxes.

LVL 7: 2 Rigs 10 Targets		LVL 6: 2 Rigs 6 Targets	
Minimum	1.2E+14	Minimum	7.0E+13
Maximum	1.4E+14	Maximum	7.0E+13
LVL 5: 2 Rigs 6 Targets		LVL 4: 2 Rigs 6 Targets	
Minimum	4.5E+13	Minimum	3.0E+13
Maximum	4.9E+13	Maximum	3.0E+13
LVL 3: 4 Rigs 12 Targets		LVL 2: 2 Rigs 6 Targets	
Minimum	1.5E+13	Minimum	8.0E+12
Maximum	1.6E+13	Maximum	8.1E+12
LVL 1: 1 Rigs 3 Targets		FF: 2 Rigs 6 Targets	
Average	4.0E+12	Minimum	7.2E+12
		Maximum	8.9E+12
NAA: 1 Rigs 1 Targets		DNAA: 1 Rigs 1 Targets	
Average	2.6E+13	Average	5.0E+12

The other requirements like homogeneity are fulfilled.

Large Volume Irradiation Facilities. These facilities have 6 irradiation rigs and they are dedicated to the neutron transmutation doping. Table 7 shows the minimum and maximum thermal flux for all the facilities.

TABLE 7. NTD irradiation facility thermal flux.

NTD: 6 Rigs	
Minimum	3.0E+12
Maximum	2.0E+13

The other requirements like axial homogeneity and thermal to fast ratio are fulfilled.

CONCLUSIONS

The RRR has a safe and high performance core design, which fulfills all the irradiation fluxes and the operational requirements.

U_3Si_2 and U-Mo FA types can be safely handled, fulfilling the cycle length operational requirement and irradiation flux performance.

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