AUSTRALIA´S NEW HIGH PERFORMANCE RESEARCH REACTOR

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SUMMARY
A contract for the design and construction of the Replacement Research Reactor was signed in July 2000 between ANSTO and INVAP from Argentina. Since then the detailed design has been completed, a construction authorization has been obtained, and construction has commenced.

The reactor design embodies modern safety thinking together with innovative solutions to ensure a highly safe and reliable plant. Also significant effort has been placed on providing the facility with diverse and ample facilities to maximize its use for irradiating material for radioisotope production as well as providing high neutron fluxes for neutron beam research.

The project management organization and planing is commensurate with the complexity of the project and the number of players involved.

I. INTRODUCTION

The Australian Nuclear Science and Technology Organisation (ANSTO) has contracted a new high performance Research Reactor – the RRR. The reactor is being designed and built by INVAP (Argentina) at the Lucas Heights Research Laboratories (Sydney) site.

The RRR has been optimized with high priority for beam tube experiments, and at the same time is provided with a large number of diverse facilities for irradiation experiments and isotope production.

The RRR is a pool-type reactor featuring a total fission power of 20 MW. It has a compact core of low-enriched uranium fuel surrounded by a heavy water reflector vessel. The reactor is at the bottom of a light-water filled pool that provides both cooling and shielding to the core.

The design incorporates state of the art technology, high neutron fluxes per unit of power, low fuel costs, two independent shutdown systems, a passive pool for decay heat removal, a containment system for extreme events, and its design is sensitive to operation and maintenance needs.

II. DESIGN ASPECTS

The RRR has been designed to deliver a high thermal neutron flux in a large volume outside the reactor core where it is accessible for experimental use. The concept has been to physically isolate the core from the utilization facilities; thus neither beams nor irradiation facilities are located inside the core itself. This feature permits a better optimization of the neutronic performance of the core and enhances reactor safety by preventing beam or irradiation activities from jeopardizing the conditions in the core fuel or control elements.

Inside the heavy water reflector that surrounds the core, and coincident with the highest neutron flux densities, are provided several neutron beam tubes, a Cold Neutron Source and positions for material irradiation.

The smaller the core volume, the higher is the neutronic performance of the utilization facilities. The limit on how small the core is has been mandated by a number of constraints, such as: the use of plate type fuel assemblies, the use of low enriched uranium fuel, the target cycle length duration, the removal of decay heat by passive means and the use of a non pressurized primary cooling system.

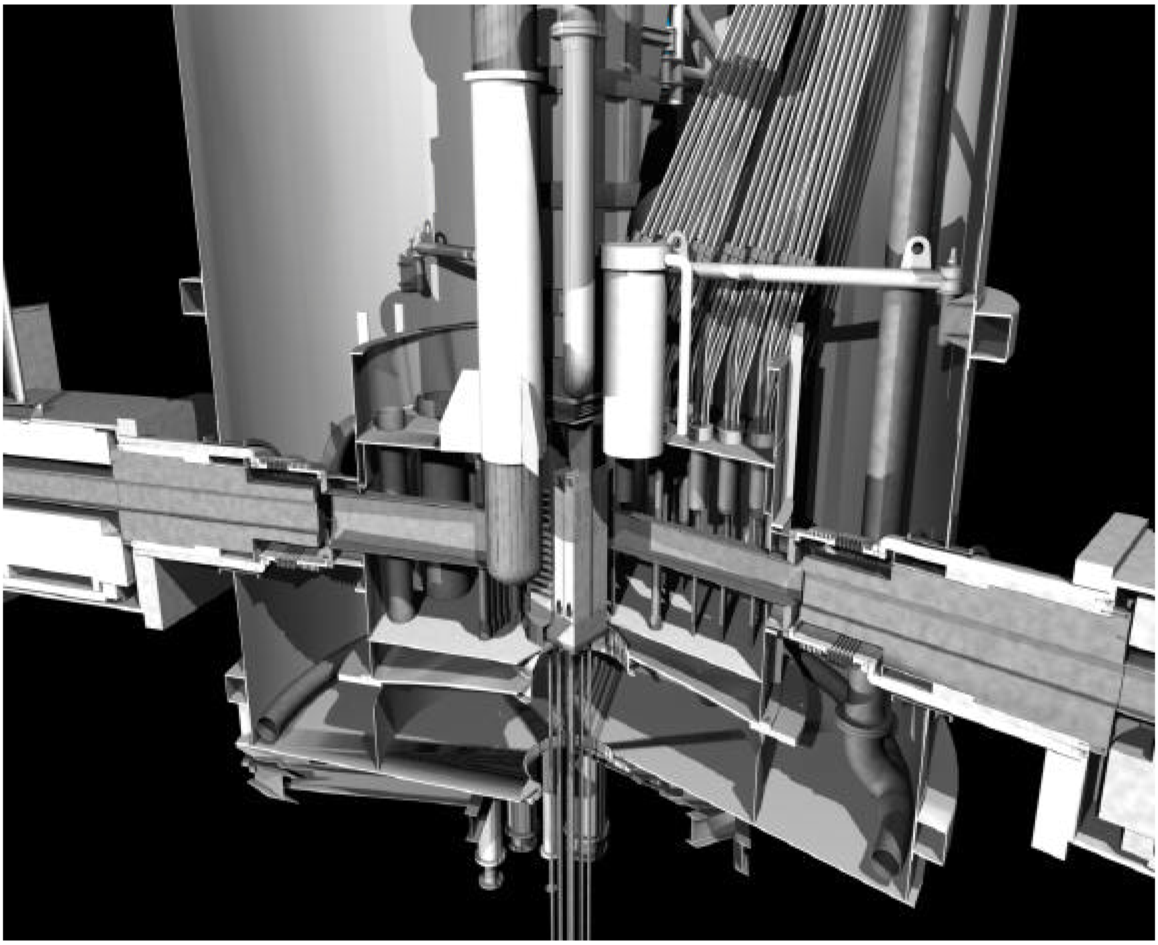

Figure 1. Core and reflector layout

A. The core

It consists of sixteen fuel assemblies of square cross-section having low-enriched uranium silicide fuel plates with aluminum cladding. The fuel plates incorporate burnable poison to help minimize the core excess reactivity throughout the operating cycle. The core is cooled and moderated by light water and features a heavy water reflector. Fission heat is removed by water circulating through coolant channels between the fuel plates. The reactor core volume is some seventy litres.

Five control rods are used to control core reactivity. Four have neutron-absorber plates inserted into the core in a cross-shaped array and the fifth has a central cruciform shaped absorber plate. The core is thus divided into four portions of four fuel assemblies each. Table 1 provides the main reactor data and Figure 1 shows the core and reflector arrangement.

Table 1. Main reactor data

Topic	Value
Reactor type	Open pool
Core thermal power	20 MW
Average core power density	280 kW/L
Core fuel load - BOC	6.25 kg U-235
Average cycle length	29 full power days
Fuel type	19.7% enriched U3Si2-Al dispersion fuel
Fuel assembly residence times	190 full power days
Number of plates per fuel assembly	21

B. Shutdown systems

The reactor has two mutually independent, redundant and diverse shutdown systems. The action of either of them is capable of shutting down the reactor and keeping it in a safe shutdown condition during the range of accident events considered in the design as well as some other events of interest.

The First Shutdown System inserts the five control rods into the core by the combined action of gravity and compressed air when requested by the First Reactor Protection System. During normal operation the central control rod is used for reactivity regulation and the other four are used for coarse reactivity compensation, under the control of the Reactor Control and Monitoring System.

The Second Shutdown System partially drains, by gravity, the heavy water from the Reflector Vessel into a storage tank beneath the core when requested by the Second Reactor Protection System.

C. Reactor cooling

The reactor core is cooled by forced circulation of light water in upwards direction, thus no flow reversal occurs in the transition from forced circulation to natural circulation cooling regimes. In addition other cooling systems remove heat from the reflector heavy water and from the irradiation facilities.

The Reactor Pool Coolant Boundary ensures availability of the water inventory required for core cooling during all foreseeable conditions. If normal electric power is lost the reactor core and the irradiation rigs are cooled by natural circulation of the pool water. The pool has a sufficiently large water inventory to provide long-term cooling without reliance on external systems or sources of power.

D. Buildings

The facility occupies 13,000 square meters, which includes the Reactor Building built in reinforced concrete housing the reactor and service systems, the Neutron Guide Hall where the neutron guide systems and the research equipment are located, and Auxiliary buildings, Offices and Cooling Towers.

The Reactor Containment System encloses the Reactor and Service Pools, Reactor Hall, and areas below the Reactor Pool that house Reactor Pool water systems and Reflector Vessel heavy water systems. The Reactor Containment System is designed to prevent or mitigate the uncontrolled release of radioactive materials to the environment.

The facility is divided in zones considering the different tasks carried out within the plant, and taking into account radiation protection, fire protection and security issues. The layout aims at providing each of the different groups interacting with the facility: beam users, reactor operators, reactor maintenance staff, radioisotope operations and visitors, with dedicated areas and appropriate circulation paths that allow segregation of their activities. At the same time some strategically placed zones promote interaction between these groups to provide integration.

III. SAFETY PHILOSOPHY

The overall safety objective for the RRR is to protect individuals, society and the environment by establishing and maintaining an effective defense against radiological hazards.

Good design practice and construction, including the use of appropriate codes and standards and a quality assurance program, will ensure reactor safety for normal operation and anticipated abnormal events.

A thorough and comprehensive design, together with operating procedures for the reactor, will ensure that radioactive releases and the resultant radiation doses are as low as reasonably achievable. The defense in depth strategy has been followed in the design of the RRR to compensate for potential human and mechanical failure and unexpected occurrences. Abnormal events are prevented, then mitigated, then accommodated, in that order; and a series of barriers will prevent, reduce or slow down releases of radioactivity into the environment.

The facility meets the regulatory requirements of the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) and complies with applicable International Atomic Energy Agency (IAEA) guidelines and recommendations.

A. Safety concept

The safety of the RRR is based on the capability to shut down the reactor under all circumstances and the prevention of fission product releases by means of successive physical barriers, namely fuel matrix and cladding, pool water and reactor building. Even in the highly improbable failure of the fuel, the reactor pool water will retain a large portion of the fission products and the rest will be retained by the containment system.

Engineered Safety Features are provided which are capable of maintaining the reactor in a safe condition under all anticipated conditions. They constitute the third level of "defense-in-depth' and are designed to prevent incidents from developing into accidents. They comply with fail-safe and reliability safety criteria.

The design incorporates many safety features and inherent safety characteristics. These include:

a) The ability to cool the reactor by use of natural circulation cooling in the event of loss of normal cooling.
b) The lack of dependence on normal power supplies to shutdown and cool the reactor.
c) The two diverse and independent shutdown systems. Each employing its own triplicated sensors, logic and actuators.
d) The large volume of low pressure and low temperature water contained in the reactor pool acts as a heat sink for every relevant accident scenario, this together with the core enclosure and its dedicated Emergency Make Up Water System (EMWS) render negligible the risk of “fuel meltdown” due to exposure to air.
e) An energy management system that ensures that the pressure in the containment remains negative during accident sequences.
f) The levels of protection against loss of coolant accidents.
g) The ability to withstand a 1 in 10,000-year seismic event and beyond and the grille protection against aircraft crash.
h) The low generation of gaseous radioactive emissions due to the use of water cooling of rigs, helium systems in high dose beam areas and a hot water layer at the reactor pool surface.

B. Safety assessment

The analysis used both deterministic methods and a level 1^+ probabilistic safety assessment. A deterministic analysis of the behavior of the reactor and associated systems following a comprehensive range of identified Design Basis Initiating Events was performed. All cases analyzed have been conservatively assessed with an assumed single failure of the protection/shutdown systems. The failure of one shutdown system and the need for a reactor shutdown by the second acting signal have also been assessed. The numerical calculations show that the reactor goes through a series of safe states following the occurrence of a Design Basis Initiating Event. No significant core or rig damage occurs in any of the assessed transients.

The assessment of individual safety systems was done by means of Failure Mode Effect Analyses.
The core damage frequency of $4x10^{-7}$ per year fully complies with regulatory limits and the selected bounding sequences are well below the frequency-dose acceptance curve.

C. Licensing

Based upon submissions by ANSTO on the site characteristices, and upon constraints ANSTO placed on the design and operation of the facility, ARPANSA issued a Siting Licence in September 1999.

A Preliminary Safety Analysis Report (PSAR), was prepared as part of the Application for a Construction Licence. The development of the PSAR involved INVAP addressing in a comprehensive way the facility’s systems and their safety analysis. The PSAR has been prepared in accordance with the IAEA Safety Guide SS 35-G 1 "Safety Assessment of Research Reactors and Preparation of the Safety Analysis Report" 1994. ARPANSA issued a Construction Licence in April 2002.

IV. NEUTRON BEAM FACILITIES

Beams of neutrons are guided to experimental stations outside the reactor shielding, where they are used as powerful probes of materials.

ANSTO is incorporating into the RRR a suite of neutron beam instruments to provide Australia with state of the art capabilities for research in wide ranging fields of science and engineering. The cold neutron source, which is a key element of many facilities around the world, will open new fields of research for Australian scientists.

Neutron supermirror guides are used to efficiently transport neutrons from the high-density neutron areas located in the Reflector Vessel to the research instruments located in the Reactor Beam Hall and the Neutron Guide Hall. Neutron beam facilities include cold and thermal neutron sources, neutron beam shutters, neutron guides and extensive areas for deploying the research instruments.

The buildings that support these facilities comprise:

a) The Reactor Beam Hall (RBH) - an area in the reactor building that accommodates the neutron beam instruments that need to be as close as practicable to the reactor.
b) The Neutron Guide Hall (NGH) - an area adjacent to the reactor building that accommodates the majority of the neutron beam instruments, workshops, laboratories, offices and a viewing gallery.

A. Cold neutron source
The liquid Deuterium type Cold Neutron Source is located close to the peak thermal flux in the Reflector Vessel. It has a maximum neutron yield with energy less than 5 meV, an operating temperature below 25 K, and serves two neutron beam assemblies located on opposite sides of the Reflector Vessel and tangential to the reactor core. The cold neutron flux at the performance measurement locations at the reactor face will be of the order of 1.4×10^{10} n cm^{-2} s^{-1} and at the performance measurement locations in the NGH will be of the order of 2.7×10^{9} n cm^{-2} s^{-1}.

The Cold Neutron Source cooling system is a double-wall liquid deuterium/helium design that promotes reliable and safe operations. Both the Cold Neutron Source cooling system and the reactor are capable of operation if the other is shut down. Postulated failures of the cold source do not affect reactor safety. The cold source is automatically monitored and controlled by the Cold Neutron Source Control System.

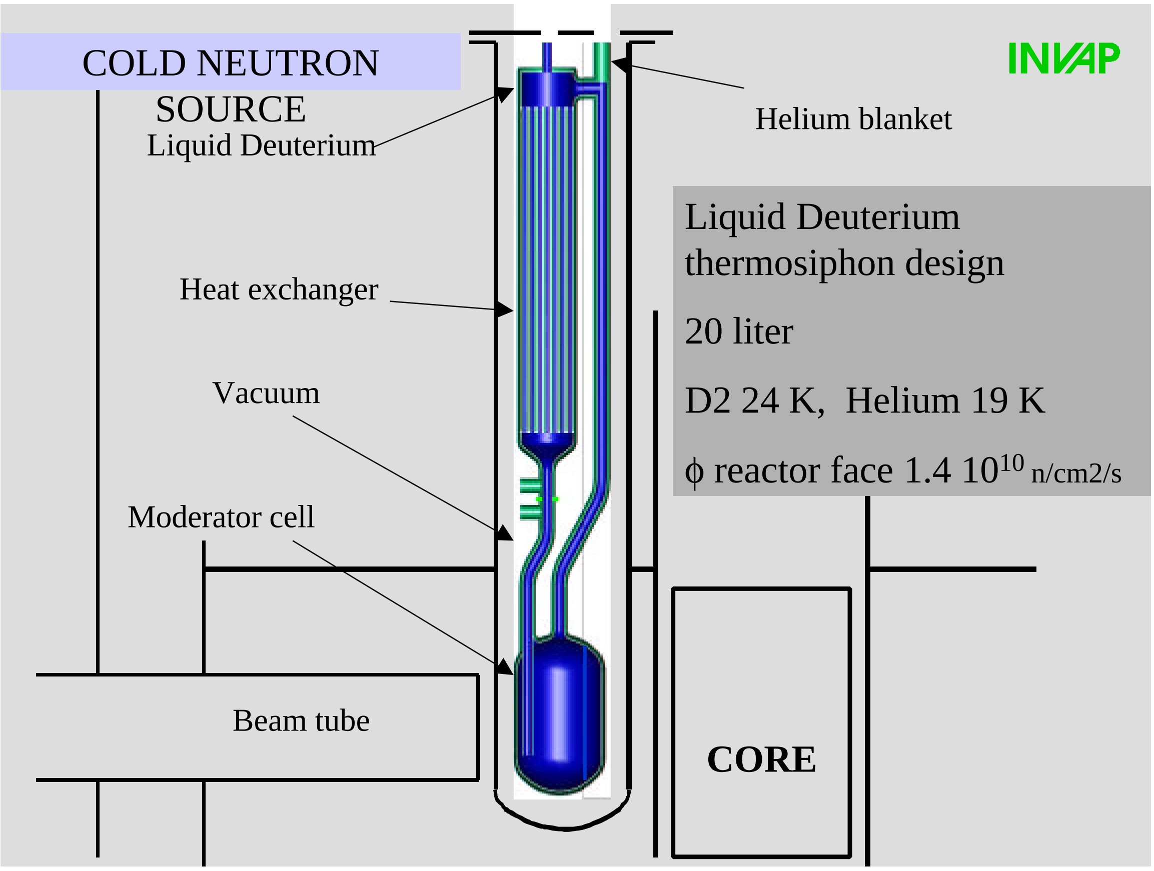

Figure 2. Cold neutron source

B. Thermal neutron source
The thermal neutron source comprises a heavy water zone located close to the region of peak thermal flux in the Reflector Vessel and serves two neutron beams located in almost opposite directions and tangential to the core. The nominal thermal neutron flux at the performance measurement locations at the reactor face will be higher than 1.6×10^{10} n cm^{-2} s^{-1} and at the performance measurement locations in the NGH will be higher than 1.6×10^{9} n cm^{-2} s^{-1}. The

neutron spectrum has a temperature in the range 40°C to 60°C.

C. Hot neutron source (future)

On the center of one of the core faces a place has been reserved for the future installation of a Hot Neutron Source (HNS). The envisaged HNS design would be based on a Graphite block heated by radiation coming from the core. It is foreseen that the HNS will operate at a temperature close to 1800 °C. One neutron beam, tangential to the core, originates at the position reserved for the HNS. Until the HNS is installed, the beam will be used as an additional thermal beam.

D. Neutron transport systems

There are five neutron beam assemblies leaving the reflector vessel in a tangential arrangement with respect to the core. Two neutron beam assemblies (one thermal and one cold) deliver neutrons towards the NGH which is located to the north of the Reactor Building. The neutron beam assembly serving the future HNS is directed into the RBH in a westerly direction. The remaining two neutron beam assemblies (one thermal and one cold) leave the reactor in a southerly direction. The facility layout allows for the future construction of a second Neutron Guide Hall to the south of the Reactor Building. Except for the HNS beam assembly that provides for two neutron guides, all other beam assemblies have capacity for three neutron guides each.

The neutron beams leave the reflector vessel, traverse the reactor pool liner and the shutters embedded in the reactor block. The shutters contain sections of neutron guides that penetrate the block to maximize the neutron transport from the core to the experiments.

Neutron supermirror guides are built by sputtering multiple successive layers of titanium and nickel on glass slabs. The guides feature a critical angle of two and three times that of nickel. Guides are contained inside a vacuum housing to ensure optimum transmission and alignment stability.

V. IRRADIATION FACILITIES

Radioisotopes are produced by introducing targets into dedicated irradiation positions in the reflector vessel. Numerous irradiation positions are provided in the reflector tank, some are water-cooled and other are served by pneumatic transport systems. Facilities for irradiation of Silicon ingots for NTD and several hot cells are also provided.

A. General purpose irradiation facilities

They comprise fifty tubes that run from two pneumatic transfer hot cells to locations in the reflector vessel having neutron fluxes ranging from $2.4x10^{12}$ to 1.0×10^{14} n cm^{-2} s^{-1}

Target materials are loaded into aluminum or titanium containers and are transferred to the irradiation positions in the reflector by nitrogen. There they can remain for periods ranging from seconds to weeks. The nitrogen gas is used both for transport and cooling and consequently targets are limited to those that can be adequately cooled by the nitrogen gas.

B. Bulk production irradiation facilities

They comprise seventeen irradiation tubes running vertically through the reflector vessel. They are water-cooled. Irradiation rigs, which can be removed with the reactor at power, will accommodate up to five target cans and have a cooling capacity of 125kW. They will be used primarily for the irradiation of low enriched uranium for the production of Mo99, tellurium dioxide for the production of I131 and iridium metal for the production of lr192.

C. Large volume irradiation facilities

They comprise several irradiation tubes in the reflector vessel that will be used to irradiate mineral and other samples mainly for the minerals industry, and for the neutron transmutation doping of single crystal silicon ingots for the electronics industry. To ensure irradiation homogeneity within the Silicon ingots, they are provided with neutron flux flatteners and are rotated by means of a hydraulic system.

D. Neutron activation laboratory

A laboratory has been provided in the reactor building for the analysis of samples that are irradiated in large pneumatic conveyor irradiation tubes for only a few minutes. They travel from the reactor to the laboratory in 3 seconds for immediate analysis of the very short activation products.

E. Neutron transmutation doped silicon laboratory

This laboratory is provided for the post irradiation scanning, cleaning and packaging of the silicon ingots.

F. Shielded hot cells

The facility is provided with four shielded hot cells to allow safe and efficient handling of the radioisotope targets and their delivery to the ANSTOs adjacent radioisotope processing facilities. The irradiated targets are handled as sealed sources within the RRR. The total system is designed for the minimum involvement of staff, and for the minimum exposure of those staff that are involved to radiation from the targets being transferred. The design is particularly successful in this latter regard.

Two Pneumatic conveyor hot cells are provided for the transfer of targets from the irradiation tubes to the radioisotope production buildings.

An additional isotope Transfer hot cell is provided for the unloading of the bulk irradiation rigs and for the transfer of the targets removed to the Loading hot cell.

VI. PROJECT MANAGEMENT & ORGANISATION

The construction of the RRR represents an important undertaking for INVAP and Australian private companies. Expertise is drawn from INVAP seasoned management and design teams and from strategic associations with the PNPI (Russia) and MIRROTRON (Hungary) for the Cold Neutron Source and the Neutron Guides respectively. INVAP is responsible for the overall delivery of the project that involves the co-ordination of a team of some twelve companies from around the world.

A Project Management Plan (PMP) establishes the overall organizational grounds, responsibilities and links between all the parties participating in the project. The PMP is the key to other general and phase specific plans that are the basis of the project management effort. The project is run under an ISO 9000 certified system, covering design as well as construction activities.

Communication and reporting to the ANSTO is done on a regular basis allowing a close control of the project progress and status.

A. Planning and scheduling

The RRR project schedule for the RRR has a duration of 66 Months. The project is organized through a Work Breakdown Structure (WBS) with more than 300 work packages that cover the different phases: Launching, Preliminary Engineering, Detail Engineering, Construction, Manufacturing and Procurement, Installation, Pre-operational Testing and Commissioning.

The Project Master Schedule (PMS) shows the time frame and precedence for the execution of the different work packages and is an important tool in the planning and control of the project.

The contract for the design, construction and commissioning of the Replacement Research Reactor was signed in July 2000. This was followed by the completion of the detailed design and an application for a construction license was made in May 2001. The Construction License was issued on 4th April 2002 which was followed immediately by the commencement of the excavations. In Table 2 are indicated the main project milestones.

The project suffered a 4 month delay during the second half of 2002 when two fault strands were discovered during the excavation of the site. A thorough investigation was undertaken using a wide range of techniques and drawing on the expertise of many specialists. These studies demonstrated that there had been no movement of either fault in at least 5 million years and the faults were assessed as incapable. Regulatory approval to proceed with work on the site was subsequently granted.

Table 2. RRR Project Milestones

Milestone	Time since project start date
Contract signature	0 month
Presentation of PSAR	10th month
Construction start	21th month
Construction and installation complete	55th month
Nuclear commissioning complete	61th month

B. Risk Management

A Risk Analysis and Management Plan is in place to control, have early warning and allow development of contingency plans to address any technical, organizational or commercial issue that may threaten the project schedule, budget or performance of the final product to be delivered. Relevant actions are taken to provide early detection of any significant change in the risk levels, detect new risks and ensure that tasks and measures are in place to keep risks under control.

C. Local Industry Participation

While INVAP has the overall responsibility for the delivery of the project more than fifty per cent of the RRR project will be sourced from within Australia. To this end INVAP has formed an alliance with a large Australian engineering and construction company (John Holland Evans Deakin Industries Joint Venture). Australian companies have participated in the project since the tender and they are responsible for half of the project work packages encompassing engineering, construction and installation activities.

D. ANSTO Participation

ANSTO oversees all the project activities. During design it has participated actively as part of the design teams and in formal design review meetings, during construction it will control the activities by means of nominated witness and hold points indicated in the Construction Inspection and Test Plans.

VII. CONCLUSIONS

The reactor being constructed is a world class neutron source of great flexibility, high productivity and very high availability.

The reactor will also significantly enhance the ability to supply industrial and medical radioisotopes to satisfy the demand into the future. This will be done with a reactor that has many inherent safety features and very low levels of risk.

The construction started in early April 2002 following the issuance of a Construction License by the Australian Regulator (ARPANSA).