INSTALLATION AND TESTING OF THE OPAL (ANSTO) COLD NEUTRON SOURCE

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ABSTRACT

On-site testing of Australia's new Cold Neutron Source (CNS) commenced in July 2005 at ANSTO, Sydney. CNS testing at OPAL is on-going and commissioning of the integrated reactor systems is due to commence in late 2005.

INVAP, the principal contractor, has undertaken the design and installation of the CNS system, in conjunction with PNPI Gatchina and Air Liquide. The CNS has a nominal refrigeration power of 5000W, and operates with a sub-cooled liquid deuterium moderator at 24K. The Moderator Chamber has been constructed from AlMg5, and the Vacuum Containment from ZrNb2.5%. A cold neutron flux of 1.4*10E14 n/cm^2/s is expected in the energy range <10meV, with a peak in the energy spectrum at 4.2meV, at the reactor face.

The on-site acceptance tests of the CNS refrigeration and associated systems, along with plans for the operation of the CNS, are discussed in this paper.

INTRODUCTION - GENERAL FACILITY DESCRIPTION

The OPAL Cold Neutron Source is a liquid deuterium moderated source operating with a nominal refrigeration capacity of 5 kW. A cold neutron (<10meV) flux of 1.4*10E14 n/cm^2/s has been calculated at the reactor face. An update on the progress of the installation and testing of the cold source is provided below.

INVAP is the principal CNS contractor, responsible for the design, installation and commissioning. They have been directly responsible for the development of the moderator, vacuum and gas blanketing systems. PNPI was sub-contracted for the design and fabrication of the in-pile components (i.e. the Vacuum Containment, moderator chamber, thermosiphon and upper moderator). Air Liquide/DTA France has supplied the cryogenic refrigeration system. Further detail on the design and development of the CNS, and the overall OPAL reactor facility is only summarised below, as it has been detailed in an earlier paper [1].

The Moderator System is comprised of essentially passive components. During cryogenic conditions approximately 1/3rd of the entire deuterium inventory is condensed within a 20L moderator chamber (AlMg5) and the associated thermosiphon loop. The deuterium is cooled to an average temperature of 24K, via natural convection through the thermosiphon. Under warm conditions the bulk of the deuterium gas is stored in two 10m^3 buffer tanks. The entire Moderator System is jacketed. Deuterium may be disposed of through the reactor's heavy water de-combination system.

The Thermosiphon and Moderator Chamber are cooled by helium gas. The helium Refrigeration Cryogenic System (CNS-RCS) utilises the Brayton cycle to deliver helium at 19.8K. The helium is compressed by two 250kW compressors, one of which is fitted with a variable frequency drive, in order to reduce power consumption during stand-by (warm) operating periods.

The CNS Vacuum System (CNS-VS) consists of two sets of vacuum pumps, housed in a blanketing vessel. A pump set operates continually, and in the event of an in-pile cooling failure (during warm mode) it can inject helium into the Vacuum Containment space to break the insulation.

The Vacuum Containment has been made from zirconium alloy ZrNb2.5%.

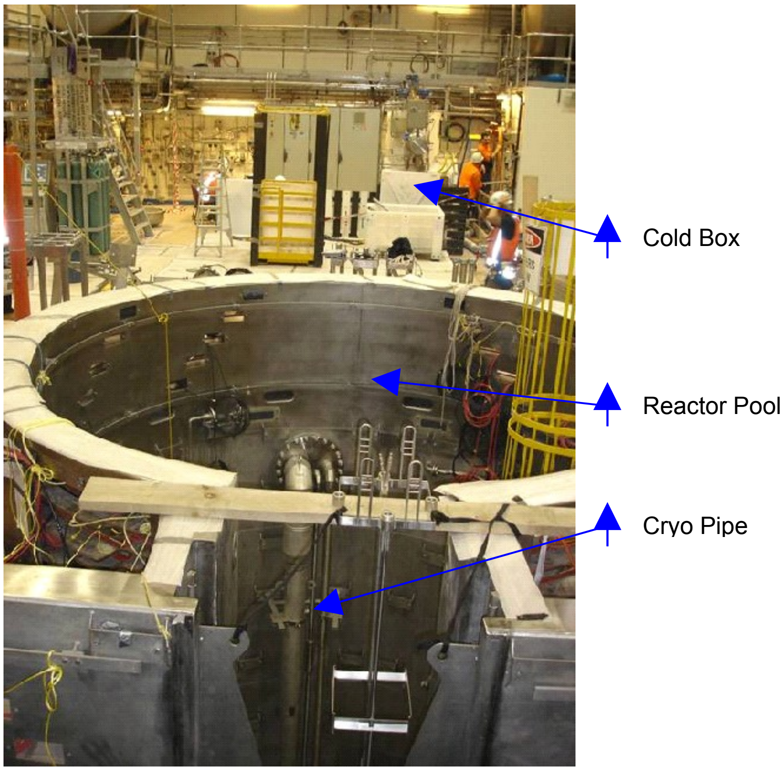

Figure 1. CNS Installation in the Reactor Hall

The CNS will support the following instrumentation: small angle neutron scattering, cold quasi-laue diffractometer, and a polarisation analysis spectrometer.

PROTOTYPING AND FACTORY ACCEPTANCE TESTS

The CNS in-pile prototype tests where performed by INVAP and PNPI in Gatchina. The aim of these tests was to demonstrate that the thermosiphon was able to remove the required heat load from the deuterium moderator by natural circulation during normal and stand-by operations as well as verify the overall system behaviour during transients (mode switch and failure scenarios). A prototype in-pile assembly (1:1 scale) was connected to a helium refrigeration system, vacuum system, and deuterium buffer tank. The assembly allowed for measurement of deuterium temperatures at different points in the convection loop. Nuclear heating was simulated by two heaters, one to heat the deuterium and the other the helium.

During normal (cryogenic) operation, 4300 W was successfully removed by the thermosiphon. Up to 2650 W was removed during stand-by (warm) operation.

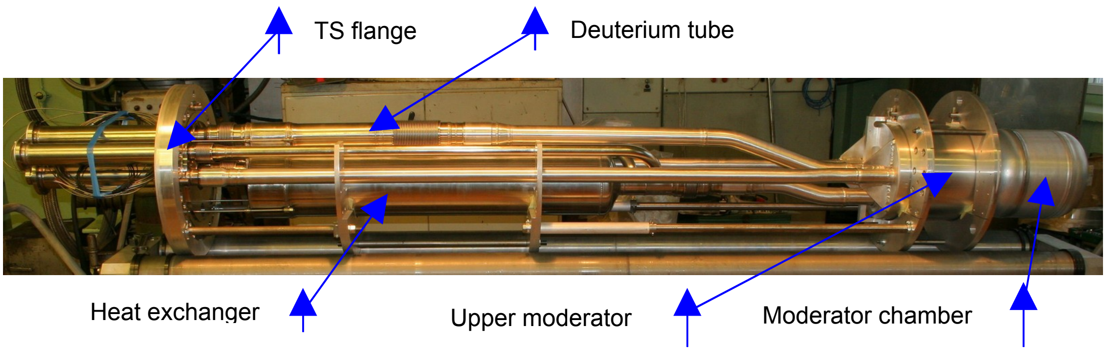

Figure 2. CNS In-pile Assembly

The Cryogenic Refrigeration System (CNS-RCS) was subject to factory acceptance tests at Air Liquide's facility in Sassenage, France, in early 2004. The aim of these tests was to demonstrate the RCS performance during the different operating modes, the transition between operating modes and the system response to trips. The testing program included the following:

- Normal Operation (NO) at 18K
- Stand-by Operation (SO) at 310K
- NO to SO transition (warm-up from 18K to 310K)
- SO to NO transition (cool-down from 310K to 18K)
- Fast warm-up to Stand-by Operation (rapid NO to SO transition)
- Normal Operation mode power test (Normal Operation with a simulated heat load)
- System behaviour test with a reactor trip simulation
- Power reduction and failure simulations

The acceptance tests demonstrated successful steady state operation in normal and stand-by modes. The refrigeration power was measured to be greater than 5900 W in Normal Operation (cryogenic) mode (exceeding the design requirement of 5 kW). The heat removal in Stand-by Operation (warm) mode was measured at 4600 W.

Because of the differences between the setup of the cryogenics system for the factory acceptance tests and the final design configuration, it was not possible to accurately model the hydraulics of the final system in detail. As a consequence, some required system's responses under transients were not tested. During the pre-commissioning, carried out during July 2005, the fully assembled cryogenic system (except for the CNS thermosiphon and the cryo-pipes, which were replaced by a calibrated by-pass) was tested, allowing for all the remaining responses to transients to be fully addressed. During this later stage the cryogenics system was satisfactorily tuned and tested.

CNS SAFETY REPORT

A dedicated Safety Report has been prepared for the CNS. It has been shown in the report that the CNS does not affect reactor safety. Despite its relative proximity to the reactor core, the report demonstrates that it can be effectively considered as isolated from the reactor system, due to the strength of the Vacuum Containment. The vacuum containment has been designed for an internal pressure of 1.6MPa, enough to withstand a hypothetical deuterium-oxygen explosion within it.

Three levels of prevention have been incorporated into the process design to prevent the occurrence of a deuterium-oxygen explosion. To prevent the formation of a deuterium oxygen mixture the entire deuterium system is surrounded by a gas blanket. To avoid an ignition source there is protection from static electricity, and the Vacuum System prevents oxygen from reaching the in-pile assembly. Thirdly, the Vacuum Containment is able to protect the reactor facility from any damage during a hypothetical explosion.

The CNS is automatically controlled by the facility's Control and Monitoring System (CNS-CMS). All protection related parameters are monitored by a dedicated CNS Protection System (CNS-PS, Safety Cat 2). The main protection action is to cause a reactor shutdown, and thereby reduce the heat load on CNS components. The CNS Protection System is not a Nuclear Safety System, and only functions to protect the CNS from material damage.

INSTALLATION

Installation of CNS components commenced in March 2005, after receipt of the helium compressors, oil skid and cold box. The moderator system and vacuum system blanketing boxes where installed in June 2005, along with all the associated gas blanketing.

The Vacuum Containment has been made at PNPI from the following parts: one seamless ZrNb2.5% tube ø 345 mm with a 10 mm wall thickness and 3000 mm length, flange, end cap and centering pin. Just two join welds by EBW were applied for assembling of the raw vacuum containment. After welding, the raw vacuum containment was machined with good accuracy, good linearity and to fine tolerances. The lower section of the Vacuum Containment has only 3± 0.15 mm thick wall. Such small tolerances were required to get the small gap between the Vacuum Containment wall and the neutron beam tip with a good precision.

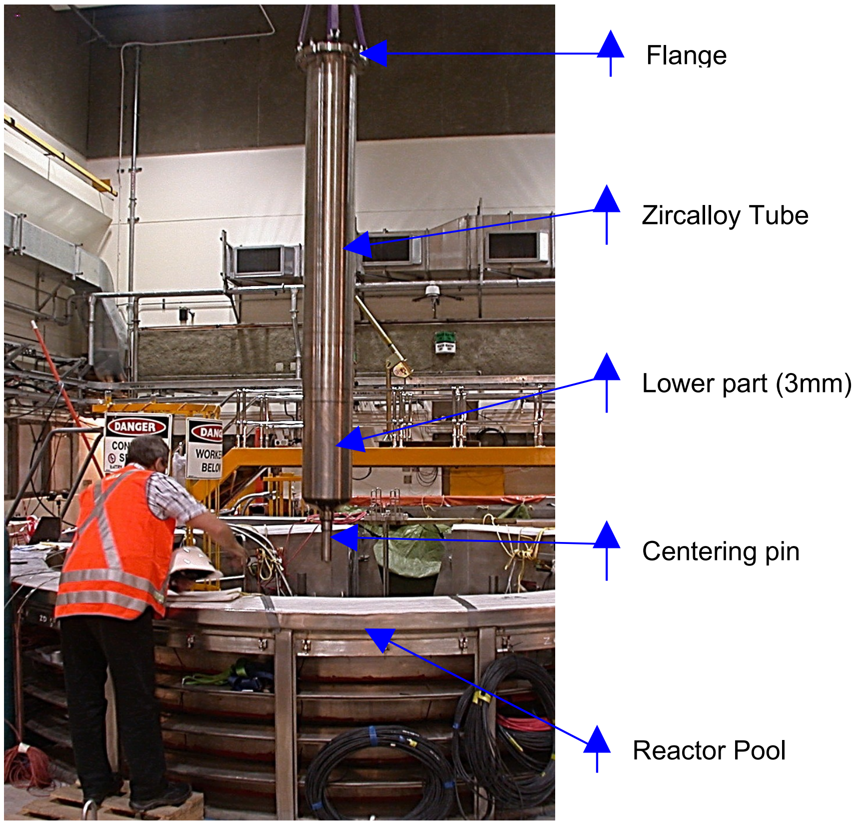

Figure 3. CNS Vacuum Containment during installation into the reactor vessel

The Vacuum Containment was fitted and installed in August 2005, along with the majority of the cryopipe. In order to guarantee the separation between the beam tubes and the Vacuum Containment an alignment pin for the Vacuum Containment was redesigned to allow for on-site adjustments. Installation of the in-pile assembly is scheduled for mid September.

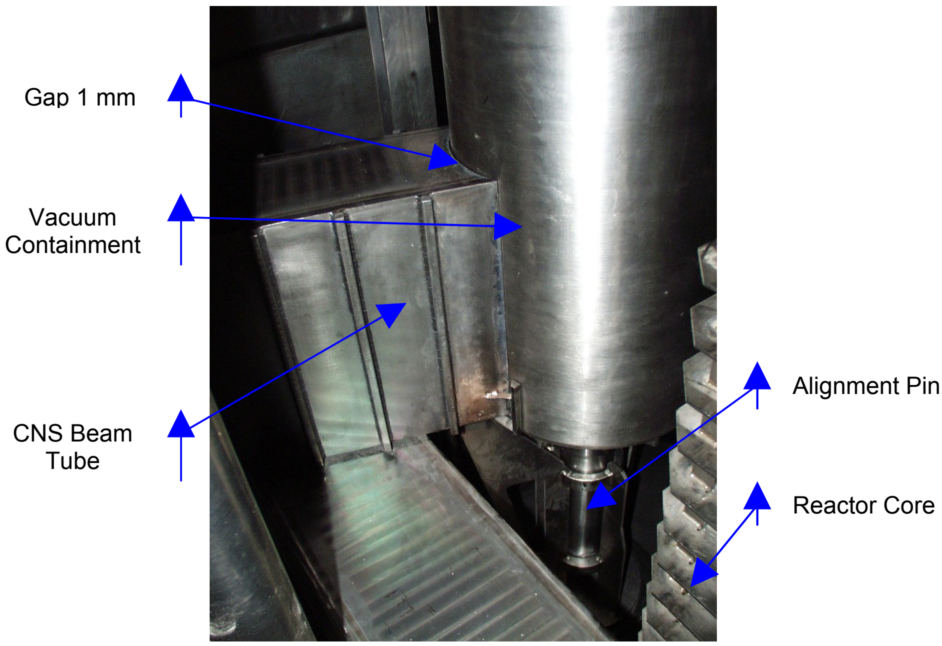

Figure 4. CNS Vacuum Containment During a Trial Fit in the Reflector Vessel. (Beam tubes and heavy water sparger are shown)

STATUS OF CNS COMMISSIONING

Three main tests have been scheduled for the CNS refrigeration system, prior to the loading of fuel. The first two refrigeration tests, with a helium bypass loop fitted to the cold box, and at the end of the cryopipes, respectively, have been completed. The third test, is with the CNS in-pile assembly connected, and involves the liquefaction of deuterium. It will of course require the full operation of the CNS Protection System.

The by-pass loops installed, during the first two on-site tests, incorporated appropriately sized orifices to model the in-pile pressure drop through the cryogenic heat exchanger and moderator chamber. As a result of this the dynamic behaviour of the CNS was much better modelled than during the factory acceptance tests.

The CNS-RCS has been well tuned during these tests. Of major interest, during the tuning of the CNS-RCS, was the guarantee of a helium flow rate greater than the low flow alarm and trip value, at all times during a transient between the normal and stand-by operating modes. The corresponding difficulty was also the maintenance of a low enough helium pressure at the moderator chamber to prevent triggering the high pressure alarm or trip. The flow and pressure parameters are expected to be even better controlled when the by-pass is moved to the end of the cryopipe, due to the increased cryogenic helium volume, and the slower thermohydraulic response.

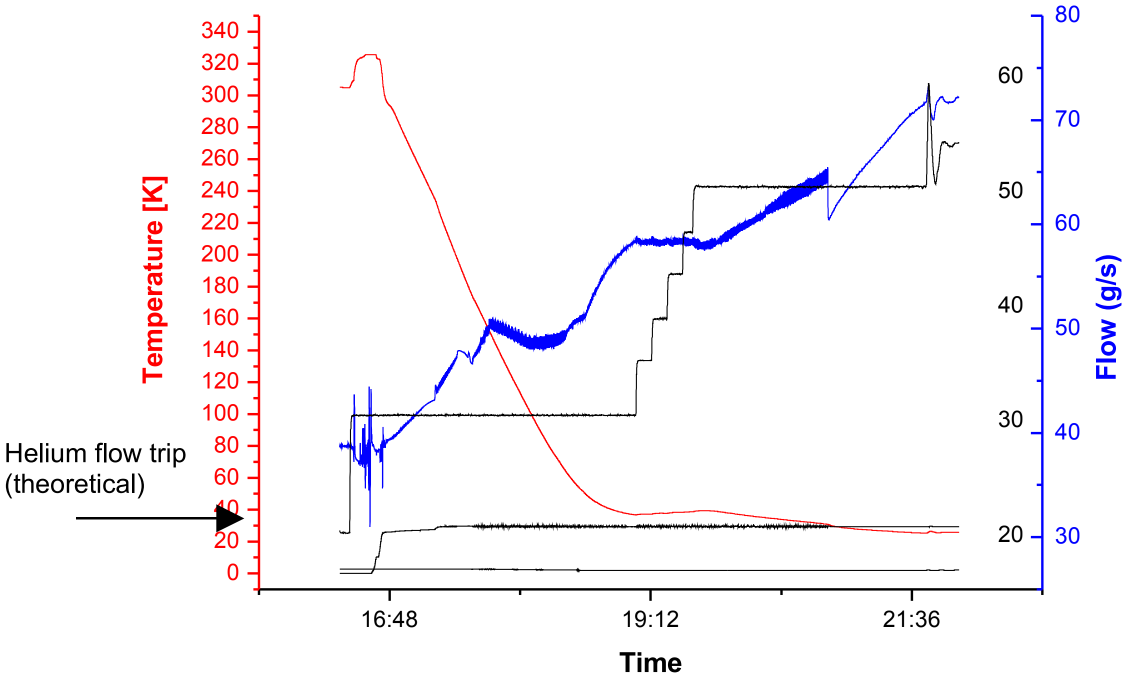

Figure 5. On-site testing of the CNS-RCS. Transition from SO to NO mode. (Reactor Power is scaled in terms of 100's of Watts)

During these tests it has also been verified that the failure of one of the two helium compressors, during normal cryogenic operation does not lead to a reactor trip. The flow to the in-pile assembly was maintained above the low helium flow trip set point (based on a theoretical set point conversion for the by-pass loop).

The heater, internal to the cold box, has been used not just for regulation of the cryogenic helium temperature, but also to simulate the reactor power. This has allowed the attenuation of the turbine outlet temperature, and the system response to reactor trips, to be demonstrated. During the steady state Normal Operation (cryogenic) mode power test a cryogenic refrigeration power of 6.1kW was measured.

Testing of the CNS integrated with the reactor facility, will occur with sequential increases in reactor power. At each reactor power a steady state (thermal equilibrium) will be reached for the CNS and heat load calculations performed. Loss of cooling tests are also performed at each power level. An outline of the preliminary testing program is given below.

Power Level	Transitions NO - SO	NO mode			SO mode			
		Thermal Balance	FSS (loss of cooling)	SSS	Thermal Balance	FSS (loss of cooling)	SSS	Power Supply Loss
1 MW	X	X	X					
3 MW	X				X	X		
5 MW	X	X	X	X				
10MW	X				X	X	X	X
15MW	X	X	X		X	X		
20MW	X	X	X		X	X		X

Figure 6. Reactor facility integrated system tests with the CNS at different power levels.

OPERATIONAL ISSUES

OPAL is a multipurpose research reactor, used for beam research as well as silicon neutron transmutation doping (NTD) and radiopharmaceutical production. In order to maximise isotope production the CNS has been designed with a stand-by mode, which allows major CNS components to be out of service without shutting the reactor down.

The CNS is able to operate in three different modes.

- Normal Operating Mode (NO): All CNS systems are operable. The refrigeration system provides enough cooling power (5000 W design) to liquefy the deuterium moderator, and keep it sub-cooled. Both RCS helium compressors are operable. The vacuum system is continuously running.
- Stand-by Operating Mode (SO): The deuterium moderator is gaseous, and the refrigeration system provides enough cooling power to maintain it at an ambient temperature (~ 300K). During this mode the cold box is by-passed and only one RCS helium compressor (fitted with a variable frequency drive) operates. The reactor is still able to operate at full power, and this mode is ideal for some CNS-RCS maintenance tasks, or a reduction in electric power consumption.
- Halt Mode: The deuterium moderator is gaseous, and the CNS-RCS is shutdown. During this mode deuterium may be loaded, or unloaded to the heavy water re-combination system. In this mode the reactor must be shutdown.

Currently it is foreseen to transition the CNS to Stand-by Operation (warm) mode during each of the monthly two day reactor shutdowns, for inspection and maintenance tasks.

The CNS is also fitted with a feature to decrease the time to warm-up. A Fast Warm Up procedure accelerates the rate of helium heating, and hence the rate at which cold deuterium vapour is warmed up during a NO to SO transition.

In the event of a loss of CNS-RCS helium flow in stand-by mode the in-pile assembly will slowly heat up due to nuclear heating (whilst the reactor is in operation or for 24 hours after reactor shutdown) and could cause in-pile damage if not corrected. In such an event the reactor shuts down the CNS and after a 5 minute delay the vacuum within the Vacuum Containment is broken with helium. This will allow heat conduction out of the in-pile assembly into the heavy water reflector. Spurious triggering of this helium into the Vacuum

Containment, during Normal Operation (cryogenic) mode (which would be detrimental to the CNS) is prevented by the CNS Protection System.

ACKNOWLEDGEMENTS

This paper describes the current status of the OPAL CNS, and the authors would like to thank all the participating groups for their contributions; INVAP (Bariloche, Argentina), ANSTO (Sydney, Australia), PNPI (Gatchina, Russian Federation).

[1] Development of the RRR Cold Neutron Source Facility, N. Masriera et al., IGORR 9