PROGRESS WITH THE AUSTRALIAN REPLACEMENT RESEARCH REACTOR

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ABSTRACT

Construction of the new Australian Research Reactor, the replacement for the now 46 year old HIFAR research reactor, is approximately 80% completed. Construction of the reactor facility began in April 2002 at ANSTO's Lucas Heights site near Sydney and commissioning is still on track for late 2005. Some details of the progress of construction and licensing and an outline of ANSTO research related to the use of Zircaloy-4 in the core region and reflector vessel of the reactor are given.

1 Introduction

ANSTO's Replacement Research Reactor (RRR) is a replacement for the HIFAR research reactor which is reaching the end of its useful life. The RRR design is for a 20 MW pool-type research reactor which is light water-cooled and heavy water moderated. The RRR will be a multi-purpose reactor optimised for production of radioisotopes and for neutron beams for materials research. The contract to build the RRR was awarded to the Argentinian company, INVAP, in July 2000 at a cost of A$297 million (in 1997 dollars).

In this paper we present information on the status of the licensing process with the regulator and then report on progress with the construction of the reactor. Finally we give an overview of the materials research at ANSTO that has been conducted to assist with review of the design and with a view to assuring reactor component integrity and safe operation over its lifetime.

2 Licensing Progress

In accordance with the *Australian Radiation Protection and Nuclear Safety (ARPANS) Act 1998* a facility licence must be issued by the Australian Radiation Protection and Nuclear Safety Agency (ARPANSA) for the construction and operation of the new research reactor. In deciding whether to issue a licence the CEO of ARPANSA "must take into account the matters (if any) specified in the regulations, and must also take into account international best practice in relation to radiation protection and nuclear safety".

The licensing process consists of several stages:

2.1 Site Preparation

An application to prepare the site was submitted in April 1999. The application contained information describing the purpose of the replacement reactor facility; a description of the reactor facility and the site; the siting safety assessments; and a description of plans and arrangements of how ANSTO proposed to manage the reactor facility.

Importantly the application also included the Environmental Impact Statement (EIS), Environment Australia's evaluation of the EIS and the Environment & Heritage Minister's recommendation on the Environmental Assessment.

In September 1999 ARPANSA issued the site preparation license. This allowed clearing and grading of the site and preparation of access roads but not the digging of foundations.

2.2 Facility construction

Following the assessment of tenders and the signing of the contract with INVAP in July 2000, the application for a construction licence was lodged in May 2001. The application included organisation arrangements, construction and test plans, and the 11 volume *Preliminary Safety Analysis report (PSAR)*. A *Probabilistic Safety Assessment (PSA)* was provided as an appendix to the PSAR. In addition to assessment by ARPANSA staff, the application was subject to public submissions, a peer review by an IAEA team and scrutiny of specific issues by the Nuclear Safety Committee (an advisory body created by the ARPANS Act). The licence allowing construction and testing up to, but not including, fuel loading was issued in April 2002. There are several conditions attached to this licence including the requirements to "gain the approval of the CEO of ARPANSA prior to commencing construction and prior to commencing commissioning of any item important to safety".

2.3 Application for the Operating Licence

This application to allow fuel loading and hot commissioning was submitted in September 2004 and ANSTO is looking for approval before November 2005 to meet the current schedule for fuel loading. The application has 5 parts:

- Part A - General information
- Part B - Plans and Arrangements for Managing Safety. There are separate plans for Maintaining Effective Control; Safety Management; Radiation Protection; Radioactive Waste Management; Ultimate Disposal; Security; Emergency; and Environmental Protection
- Part C - 20 volume Safety Analysis Report (SAR) and associated documentation.
- Part D - Operational Limits and Conditions
- Part E - Detailed plans for hot commissioning

In addition there are supporting documents, including the plant operations manuals. Cold commissioning is planned to continue up to September 2005 and the results of this testing will be submitted to support the operating licence application

3 Construction Progress

Following the issue of the construction licence in April 2002, site work was halted in June when excavations revealed geological faults in the bedrock. A three month investigation by Australian scientists and an international expert in seismic analysis nominated by the IAEA demonstrated conclusively that the absolute minimum age of last movement of the fault was 5 million years and ARPANSA allowed construction to proceed in October 2002.

By September 2004, total project progress measured by expenditure is over 80% complete. The detailed engineering, construction and procurement stages are virtually complete and plant installation is over 50% complete.

3.1 Buildings

The Neutron Guide Hall building including the offices reached practical completion in September 2004. Work on the reactor building is nearing completion.

3.2 Reactor plant

The reactor pool and service pool have been installed and pouring of the concrete reactor block around them is 95% complete. Primary cooling pumps, heat exchangers and many reactor system pumps have been installed.

3.3 Electrical plant

11 kV electrical system installed and testing is in progress. 415 V normal and standby (diesel backed) boards and UPS systems have been installed. Testing of the three standby diesels is about to commence.

3.4 Auxilary plant

Secondary cooling system towers, pumps and pipework have been installed. Testing of fire, water, air and HVAC systems is in progress.

The main reactor pre-commissioning tests are scheduled for May 2005 with the major system tests (pre-fuel load Stage A commissioning) planned for August 2005.

4 Materials and Engineering Research

Since INVAP was selected in 2000 as contractor to build its design for the RRR, ANSTO has been conducting a program of related materials research. The program was based on its experience with maintaining HIFAR for the past 40 years and so has been focussed on the likely long-term behaviour of the high-risk components, ie. components critical to operation of the reactor that are subjected to neutron irradiation and are difficult to replace. The approach taken has been:

a) an examination of the likely long term irradiation behaviour of the critical components;
b) extensive finite element analysis (FEA) in conjunction with the designers to identify stress levels and critical areas;
c) establishment of a surveillance program to monitor changes in material properties over the life of the reactor.

This work has been conducted in collaboration with the INVAP designers and ANSTO has provided its comments and input for incorporation in the reactor detail design.

4.1 Zircaloy-4

Zirconium and its alloys are widely used in the nuclear industry because of their combination of good nuclear properties (low absorption of neutrons), good corrosion resistance (comparable with titanium and stainless steel) and good mechanical properties (generally higher strength than aluminium alloys). For these reasons, the core region and surrounding heavy water reflector vessel of the RRR are fabricated from the zirconium alloy, Zircaloy-4. The structure is fully welded. This has several advantages, namely

a) the structure is as light as possible in the region of the core thus enabling irradiation tubes to be positioned in the region of maximum neutron flux;
b) there are no mechanical seals that could allow leakage of light water and contamination of the reflector heavy water;
c) fabrication of the reflector vessel and irradiation facilities and beam tubes is simplified.

However, the properties of the welds are different from the parent material and it is of interest to know how the material properties change, both initially due to the welding process and with time, in a radiation environment. These data are required for modelling and finite element stress analysis of the core region over the life of the reactor.

A further consideration could also have been dissimilar metal welds, say between zirconium and stainless steel or aluminium alloys, which can be problematic in a radiation environment. However, INVAP's design has mostly Zircaloy-4 in the core region and has no dissimilar-metal welds. Aluminium (core grid) and stainless steel (fuel clamps) are used in the core but the joints with Zircaloy-4 are mechanical. and so there are not the same concerns about long term behaviour.

The mechanical properties of the Zircaloy-4 parent plate, tubes, and welds are well known and codified in the relevant standards. For properties after irradiation over the longer term, there is extensive experience from the power reactor industry, although it usually for operation at higher temperatures (~300°C) and in direct contact with fuel (as fuel cladding). This experience has shown that zirconium alloys become stronger due to irradiation hardening and are subject to irradiation growth, ie. a physical lengthening of components [1,2]. In the case for example of CANDU pressure tubes, the ~6 m long tubes increase in length by 4-5 mm per year of operation [3], necessitating eventual tube replacement. Irradiation growth occurs to a lesser extent at the typical operating temperatures of research reactors, but it can be significant and has, for example, required the replacement of the Zircaloy-2 core housing in the ORPHEE reactor in 1997. For RRR, if not considered during the design phase, this radiation growth could lead to distortion or cracking of the structure and the need for unplanned remediation or replacement. The growth thus represented a design uncertainty and a risk for the 40 year design life of the reactor.

A review of the literature showed that at the operating temperature of the RRR, ie. less than 100°C, there is little likelihood of the so-called breakaway irradiation growth found at higher temperatures occurring. The data are shown in Figure 1 and suggest that total elongation will be less than 1% at a dose of 4.5 x 10^{26} n/m^2 which is the expected radiation dose to the core region over the planned 40 year life of the reactor. The possible effects of this level of elongation have been accommodated in various ways in the RRR design by INVAP.

In order to verify the results of Figure 1, an experimental program has recently been initiated at ANSTO to measure the radiation growth of actual Zircaloy-4 parent plate material used in the fabrication of the RRR reflector vessel. We are collaborating in this program with KAERI, the operators of the HANARO research reactor. This is because HANARO has a similar all-welded Zircaloy-4 core structure and so they have similar interest in the data of Figure 1. Accordingly, KAERI Zircaloy-4 specimens made from archive material from the HANARO reflector vessel are also included in the experimental program. The samples will be irradiated in the highest flux region of HIFAR and will be withdrawn and their lengths measured at each shutdown (every 5 weeks) over the next 2-3 years until HIFAR is permanently shut down. A photo of the rig containing the five irradiation growth samples is shown in Figure 2.

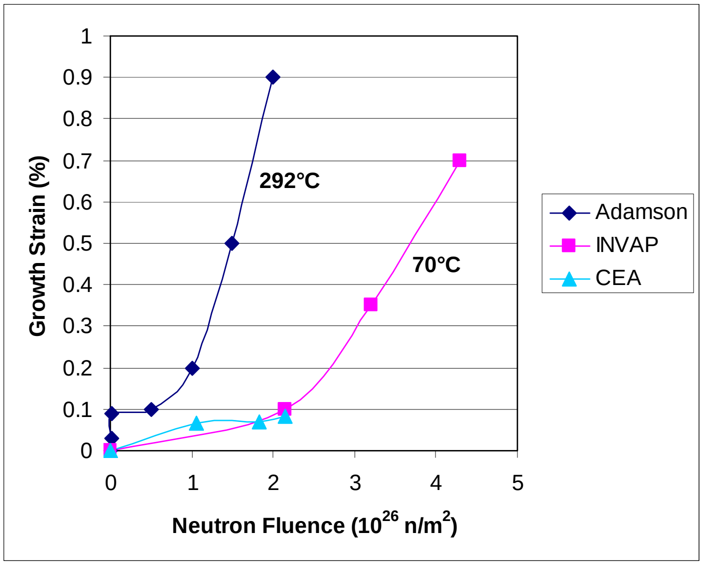

Figure 1: Irradiation growth data for Zircaloy-2 at power reactor [4] and research reactor temperatures. The CEA and INVAP data are from measurements on Zircaloy-2 and a uranium–zircaloy alloy (to increase the irradiation rate) respectively.

Figure 2: Rig containing Zircaloy-4 irradiation growth samples for irradiations in HIFAR

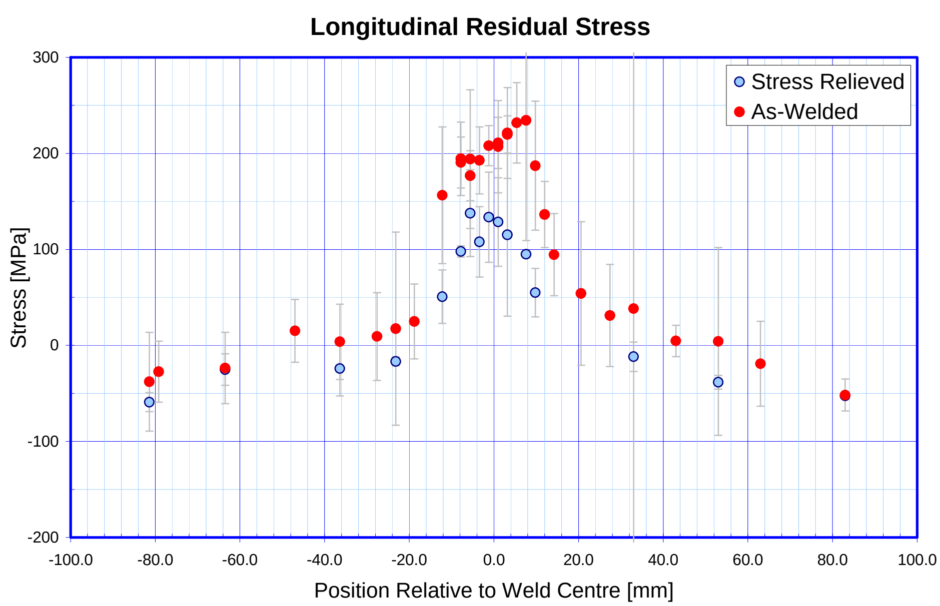

Figure 3: Graph showing results of residual stress measurements on as-welded and stress relieved weld in 8.6 mm thick Zircaloy-4 plate. The stresses are parallel to the weld direction and are greatest in this direction.

A further important piece of data for the integrity of the finite element modelling is the level of residual stresses in the welds of the core chimney and reflector vessel. These secondary stresses are important because they add to the primary (applied) stresses in any failure analysis of the structure. The levels of residual stress have been measured in a typical weld made with the INVAP weld procedures. The measurements were made using neutron residual stress measurements [5] and the levels before and after the standard stress relief heat treatment are shown in Figure 3. The results showed that the residual stresses were highest along the direction of the weld and were reduced from 240 MPa (62% of material 0.2% proof stress) to 138 MPa (35% of the proof stress). The latter figure was somewhat higher than expected but can be used in FEA models to ensure that all stresses are within design limits .

4.2 Finite Element Analysis (FEA)

Extensive FEA of the core and reflector vessel, other key components, and the reactor structure and reactor building has been carried out by INVAP as part of the design process. The models were used to verify design stresses and to predict the response of the reactor to the design-basis earthquake. ANSTO engineers have reviewed all models and results as part of the design process. They have also developed their own models for, amongst other things, security aspects and the long term behaviour of the core region. The FEA results have formed an essential part of demonstrating the safety of the reactor to the regulator, ARPANSA.

4.3 Surveillance Program

ANSTO has developed, in conjunction with INVAP, a surveillance program that will irradiate samples of core materials for the life of the RRR. This program was endorsed by the IAEA team that conducted a peer review of ANSTO's application for the construction licence for RRR and is required by the regulator. The program is based on the ASTM standard [6] for surveillance programs for power reactor pressure vessels, although the materials are different and conditions in RRR are much more benign than in a power reactor.

Samples to be irradiated have been taken from the materials used to manufacture the core components. The materials include Zircaloy-4 (plate and welds), Zr-2.5Nb (from the cold neutron source vacuum containment) and 6061 aluminium (from the core grid). The samples - pre-machined tensile and Charpy toughness samples - will be placed in a container and irradiated in a facility in a high flux area immediately adjacent to the core chimney. The program includes a timetable for samples to be withdrawn at intervals and tested to monitor any changes in mechanical properties that could affect the safety of continued operation of the reactor. The irradiation growth rate is also planned to be checked by periodic inspection and measurement of components in the core chimney region.

There will also be a corrosion surveillance program even though the RRR environment is relatively benign compared with power reactors, ie. purified demineralised light water at a temperature of 45-50ºC. A total of seven spool racks of dissimilar metal couples (Zircaloy-4/aluminium, aluminium/stainless steel, etc) will be distributed at locations around the cooling circuit. These too will be periodically removed and inspected to ensure that no abnormal corrosion is occurring. The data from the corrosion surveillance specimens will be a supplement to regular visual inspections that will be part of the routine inspection and maintenance throughout the life of the reactor.

5 Conclusions

The construction of the Australian Replacement Research Reactor is progressing well and is now more than 80% complete.

The application for the operating licence to allow fuel loading and hot commissioning was submitted in September 2004. ANSTO is looking for approval before November 2005 to meet the current schedule for fuel loading and the reactor is scheduled to be fully operational by June 2006.

A program of materials research to gain a better understanding of the materials used in the reactor and their likely behaviour over the life of the reactor is being conducted at ANSTO. A materials surveillance program will be part of the ongoing monitoring of the RRR over its lifetime.

6 References

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