1. Decision

Having considered all the material before me:

1. I find that the modification of the design of the fuel assemblies intended for use in the OPAL reactor proposed by Australian Nuclear Science and Technology Organisation (ANSTO) and detailed in its submission E0083 can be carried out safely and without undue risk to the health and safety of people and the environment. Therefore I approve the modification of the design of the fuel assemblies intended for use in the OPAL reactor under section 30(2) of the *Australian Radiation Protection and Nuclear Safety Act 1998* and Regulation 51 of the Australian Radiation Protection and Nuclear Safety Regulations 1999.

2. The approval for modification of the design of fuel is limited to fuel assemblies manufactured by CERCA

3. ANSTO may load the modified fuel into the OPAL reactor in conformity with the first stage of the return to service program that has been developed by ANSTO for this purpose and undertake testing consistent with this stage of the RTS program.

4. The existing authorisation under the facility licence authorising ANSTO to operate the OPAL reactor covers the proposed activities under the return to service program and there is no requirement for me to exercise my powers under section 36(1) of the *Australian Radiation Protection and Nuclear Safety Act 1998* to modify the authorisation granted under the facility licence.

However, I am of the opinion that certain aspects of the reactor's operations require continued monitoring and assessment and I propose to exercise my powers under paragraph 36(2)(a) of the *Australian Radiation Protection and Nuclear Safety Act 1998* to impose the following licence conditions on the facility licence that authorises ANSTO to operate the OPAL Reactor:

1. ANSTO shall, within six months of the date of imposition of the licence condition, develop a program of work, for review and approval by the CEO of ARPANSA, to characterise more fully the vibrational and other forces acting on the fuel plates and other structures in the core, the program to involve experimental work and theoretical calculation.

2. ANSTO shall complete a review of the design of the modified fuel assemblies within 2 years of the date of imposition of this licence condition in the light of the outcome of the work program required by the above licence condition and having regard to international best practice in nuclear safety.

3. ANSTO shall amend the specification for the fuel to be manufactured by CERCA to include the carrying out of the test of longitudinal strength, described in OPAL-0109-TRP-011 once per at least 20 Fuel Assemblies. Acceptance of the fuel must require a measured longitudinal strength greater than 27 N/mm.

Before exercising my powers under paragraph 36(2)(a) of the *Australian Radiation Protection and Nuclear Safety Act 1998* to impose additional licence conditions, I will allow ANSTO 28 days from the date of this decision to make any submission it may wish on this matter.

John Loy
CEO of ARPANSA
1 May 2008

2. Reaching the decision

2.1 Introduction

On 21 December 2007, I received a submission from ANSTO (E0083 – Fuel Assembly Design Modification to Incorporate a Stopper) seeking my approval to:

1. modify the OPAL fuel design
2. operate the OPAL reactor using fuel manufactured or modified[1] to that design.

ANSTO's request to modify the OPAL fuel assembly design and to operate the OPAL reactor using fuel manufactured or modified to that design arises out of ANSTO's analysis of the cause of fuel plate displacements that had been detected during the commissioning of the reactor. The fuel displacement event ("the event") is described in section 3.1.

While the event did not result in damage to the fuel and consequent exposures of workers or the public to radiation, the failure of the fuel in this manner was completely unanticipated. Such a failure was not analysed as part of the safety case for construction or operation of the reactor. Thus, while there were no radiological consequences as a result of the event, it was a serious matter that required very careful analysis and response.

ANSTO's requests for my approval are requests under the licence condition imposed by Regulation 51 of the Australian Radiation Protection and Nuclear Safety Regulations 1999 (ARPANS Regulations) for prior approval to make 'relevant changes' 'having significant implications for safety'.

In addition to assessing and making a decision on whether to approve the 'relevant changes' proposed, I also considered whether the issues raised by the occurrence of the fuel plate displacement and the analysis of the root cause of the displacement means that I should take action under section 36 of the *Australian Radiation Protection and Nuclear Safety Act 1998* (ARPANS Act) to amend the OPAL reactor operating licence.

2.2 The regulatory basis

On 14 July 2006, I issued a facility licence under the ARPANS Act that authorises the ANSTO to operate the OPAL reactor. The licence defines to 'operate' as:

i) To operate the OPAL reactor for the purpose of hot commissioning, in accordance with the program defined in:

- Commissioning Plan
- Stage B1 Commissioning Plan
- Stage B2 Commissioning Plan
- Stage C Commissioning Plan; and

[1] There are a number of matters that would need to be clarified before I could contemplate an approval that extended to the modification of existing CERCA fuel assemblies. Therefore this assessment and decision is confined to the manufacture of new CERCA fuel based upon the modified design.

ii) To operate the OPAL reactor for the purposes defined in the Application, in accordance with that Application.

Section 30(2) of the ARPANSA Act states that:

The holder of a facility licence must comply with conditions of licence.

Division 4 of the ARPANS Regulations imposes a number of licence conditions applicable to all licences issued under the ARPANS Act. Regulation 51 of the ARPANS Regulations 1999 imposes a licence condition on all ARPANSA licences requiring:

The holder of a licence must seek the CEO's prior approval to make a relevant change that will have significant implications for safety.

The Regulations define a 'relevant change' for the purposes of regulation 51 as being a change to:

(a) the details in the application for the licence; or
(b) a modification of the source or facility mentioned in the licence.

ANSTO's application for the facility licence to operate the OPAL reactor included extensive information about the detailed design of the fuel assemblies to be used in the OPAL reactor, including in particular in the Safety Analysis Report that supported the application for a facility licence authorising operation. Consequently, ANSTO's proposal to re-design the fuel assemblies to be used in the OPAL reactor is clearly a modification to the facility as defined in the scope of the original facility licence.

Given the fundamental significance of the nuclear fuel to the safety of the reactor, being the first barrier against release of radioactivity, it is clear that any modification of the fuel has significant implications for nuclear safety.

Therefore, operation of the reactor with fuel manufactured in accordance with the revised design or with fuel modified in accordance with the revised design involves changes to the details in the application for the licence and my approval for such a change must be granted before it can be effected.

In making my decision to issue the facility licence to operate the OPAL reactor, I assessed the safety of the design and construction of the systems, structures and components important for safety against the matters the legislation requires that I take into account and reached the conclusion that these were acceptable. It is now evident, as a result of the fuel plate displacement, that the design process was deficient with regard to the design of the fuel assemblies and that the fuel plates were not subject to a sufficiently effective safety analysis. (I discuss this issue further in section 5 of this statement.).

In addition to assessing and making a decision on whether to approve the relevant changes proposed, I also need to consider whether the circumstances of this request give rise to the need for me to exercise my powers under section 36 of the ARPANS Act.

Section 36 of the ARPANS Act provides:

(1) The CEO may, at any time, by notice in writing given to the licence holder, amend the licence

(2) Without limiting subsection (1), the CEO may:

(a) Impose additional licence conditions; or

(b) Remove or vary licence conditions that were imposed by the CEO; or

(c) Extend or reduce the authority granted by the licence.

The type of amendment that may be required as a consequence of consideration of this submission includes consideration of whether or not the decision to allow ANSTO to recommence operation of the OPAL reactor requires an amendment to the authorisation for operation of the OPAL reactor granted under the facility licence; and whether or not I should impose additional licence conditions on that facility licence.

If I were to exercise my powers under section 36 of the ARPANS Act, Section 40 of the Act allows for review of licence decisions, including those made under section 36, first by the Minister and then by the Administrative Appeals Tribunal.

2.3 Material before me

In making my decision, I have had regard to the legislative requirements of the ARPANS Act and all the material before me, including:

1. The ANSTO submission E0083 which included:
    - Analyses of the fuel displacement event (‘Event theme’ documents E0-E46) and conclusions as to the root causes of the event
    - Descriptions and analyses of the modified fuel design (‘Design theme’ documents D0-D39)
    - ‘Submission’ documents (S0-S6) including an executive summary (S1)

2. Questions ARPANSA posed to ANSTO provided in my letter of 15 February 2008
3. ANSTO’s responses (letters dated 14, 26 and 28 March) to my letter of 15 February including answers to the questions posed by ARPANSA, and additional documents and further testing and analysis that ANSTO had carried out in response to ARPANSA’s questions
4. The analysis conducted by Mr Horoschun as Consultant to ARPANSA, ANSTO’s response and his review of that response. This analysis is discussed in the relevant parts of this statement.
5. A report prepared by Mr Jim Snelgrove, a consultant to ARPANSA, who reviewed ANSTO’s original submission. A summary of his conclusions is at Appendix 1 of this statement.
6. Discussions of the Nuclear Safety Committee at meetings on 25 January and 21 February as documented in summary minutes of those meetings available on the ARPANSA website.
7. Responses from several members of the Nuclear Safety Committee after circulating ANSTO’s responses to the ARPANSA questions to the Committee. This response is at Appendix 2.
8. The memorandum of advice on the submission prepared by ARPANSA staff and the briefings I received from ARPANSA staff throughout the review process on the status of

their review and the formulation of questions to ANSTO and responses from the external experts.

3. The Fuel Displacement Event

3.1 Description

In July 2007, at the completion of cycle 5 of the OPAL fuel management cycle, the reactor had been shut down to prepare for cycle 6. Three fuel assemblies were removed from the core[2], another three were moved into different locations and three fresh assemblies were installed. Prior to the reactor being started up for cycle 6, the core was examined by camera to assure that the fuel movements had been carried out properly. At that point it was observed that a fuel plate was displaced from its position in a fuel assembly.

ANSTO took steps to ensure that the reactor was in a safe condition and to unload and examine the fuel assemblies in the core. These are described in document S1. The examination showed that several fuel plates had, in fact, been displaced. ANSTO also advised ARPANSA of the event.

Document E0 of the ANSTO submission presents details of the displaced fuel plates as follows:

FA	Date loaded	Number of cycles	Displacement
ARS 011	15/6/07	1	Plate 5=~530mm, plates 10,11,12
ARS 013	15/6/07	1	Plate 14=~370mm
ARS 012	15/6/07	1	Plate 14=25mm, plate 16=5mm
ARS 008	15/5/07	2	Plate 14=15mm
ARS 006	10/2/07	4	Plate 14=5mm, plate 12=<3mm
ARS 004	10/2/07	4	Plate 14=3mm, plate16=3mm
ARS 009	15/5/07	2	Plate 16=3mm

There were two fuel plates (no 5 in fuel assembly ARS 011 and no 14 in ARS 013) that were displaced by a substantial fraction of their total length (655 mm). This displacement took place in one cycle of operation. Another three to five plates had moved by noticeable amounts (14 in ARS 012, 14 in ARS 008 and 10, 11 and/or 12 under the handling pin in ARS 011 at least one of which had moved close to 65 mm preventing access by the handling hook). The other 5 plates had moved slight amounts.

Subsequent to the fuel displacement event, a review by ANSTO of previous examinations, of the core, including video footage of the core established that Plate 14 in ARS008 had moved slightly in cycle 4. It had then undergone further movement in cycle 5.

[2] The OPAL nuclear core comprises 16 fuel assemblies, each assembly being constructed of 21 fuel plates that contain the uranium fuel. After each fuel cycle (approximately one month of operation), the core is changed with some burnt fuel assemblies being replaced by fresh ones and changes in the position of some assemblies. This process is undertaken to maintain the reactivity of the core within design parameters.

There had been 26 fuel assemblies irradiated at the time of the event – 13 were of two forms of ‘start-up’ fuel assemblies with lesser quantities of fissionable uranium and 13 ‘standard’ fuel assemblies. All the displaced plates were in ‘standard’ fuel assemblies. In each standard fuel assembly, there are cadmium wires inserted adjacent to every second fuel plate, acting as a ‘burnable poison’. Eleven of the displaced plates were in positions with the cadmium wires.

All the fuel used in the reactor up to the time of the fuel displacement event had been manufactured by the Argentinean company ‘CNEA’. ANSTO had also entered a contract with the French fuel manufacturing company ‘CERCA’ for standard fuel assemblies, but these had not been used in the reactor by the end of cycle 5.

3.2 ANSTO’s submission on the cause of the displacement event

I received ANSTO’s submission in relation to the fuel displacement event (E0083) on 21 December 2007. ANSTO submitted that the root causes of the displacement of fuel plates were that:

- there was a flaw in the design of the fuel assemblies used in the reactor in that fuel plates were not restrained from upward movement by any kind of mechanical stopper.

The OPAL fuel assemblies have two aluminium side-plates with grooves into which the fuel plates are inserted and held by the process of swaging[3]. The grooves need to run out to one end of the side-plate to allow the fuel plates to be inserted during the fuel manufacture. The original design of the fuel assemblies had these grooves stopping above the top of the fuel plate. During design development, the side-plate was inverted so that the end with the grooves running out was now at the top above the fuel plates. ANSTO submits that the decision to invert the fuel assemblies was made in order to increase the strength of the attachment of the fuel assembly to the end box.

- the swaging process carried out by the fuel manufacturer CNEA did not produce a consistent and reliable joint with the sought after strength in the longitudinal direction.

ANSTO closely examined the CNEA swaging process and provided a detailed description and analysis of its potential to produce an inconsistent outcome. Longitudinal pull-tests carried out on some CNEA fuel assemblies demonstrated that the resistance in the longitudinal direction was much lower than the lateral pull strength and below the strength specified and assumed for the safety analysis report. The swaging strength for plates with cadmium wires was less than for plates without wires. ANSTO’s examination of the two plates with the largest displacements revealed variation in the amount of plastic deformation on the plate surface, and in some cases almost no deformation

[3]Swaging is a manufacturing process where two parts are fitted loosely together and then one part is mechanically deformed cold to create a permanent joint. In the manufacture of the OPAL fuel the joint between the side-plate and the fuel plate in the side-plate groove is ‘roll swaged’ by a wheel that deforms the side-plate to the immediate side of the groove.

- the normal operation of the reactor

ANSTO submitted that the drag resulting from normal flow of water at the rate of over 8 metres/second past the fuel plates and vibrational forces, together with differential thermal expansion, in combination with the inadequate swaging of the fuel plates and the lack of a mechanical stopper acting as a barrier to fuel movement caused the fuel plates to move.

To support this view, ANSTO presented data on the operation of the reactor during the 5 fuel cycles and measurements of vibration undertaken at the fuel clamps and a number of measurements taken on dummy fuel assemblies in a flow loop in Argentina.

ANSTO did not carry out direct measurements of vibration within the OPAL core. The fundamental reason offered for not doing so was that having measuring devices installed in the core would perturb the coolant flow to the point where results would be unrepresentative of the undisturbed core. There are also some safety reasons for not doing this work and the radiation fields would also affect the measurements. ANSTO verified that the vibrational pattern in the control rod guide box fastener above the core was the same as had been measured in 2006, offering some assurance that there had been no change in overall vibrational patterns in the reactor.

3.3 ARPANSA Questions

In my letter of 15 February to ANSTO, referred to above, I accepted that a contributory cause of the event was that the original design of the fuel did not have any secondary stopping mechanism, relying entirely on the strength of the swaging. I also accepted that a second cause was that the swaging process for the CNEA fuel used in the reactor was deficient.

My letter focussed on the third factor ANSTO had identified as a cause of the fuel displacement in their root cause analysis. ANSTO submitted that it was the normal operation of the reactor working on the inadequately swaged fuel plates that, in the absence of a secondary stopping mechanism, caused the displacement of the fuel plates. In my letter I wrote that:

> *I need to be fully satisfied that there were no 'abnormal' operating circumstances that may have triggered the movement. You would appreciate that if there were 'abnormal' circumstances present, they could occur again in the operation of the reactor and that there may be other safety consequences. I need to understand more fully the pattern of vibration affecting the fuel plates and within the core generally. ANSTO has undertaken some studies in this regard, but I have a number of questions as to the extent and applicability of these studies.*

I provided ANSTO with a report from an external consultant to ARPANSA (Mr Gerhard Horoschun) who had carried out some analyses that indicated that, under certain assumptions about the clamping of the plates, the flow rate of the coolant between the fuel plates may be approaching the 'critical velocity' at which point there would be hydrodynamic instability and the potential for collapse of the plates.

My detailed questions to ANSTO also covered:

- whether the measured longitudinal strength of the swaging of the CNEA plates – even though lower than required - when compared with the lower drag force calculated as applying to the plates indicated that other forces must be working on the plates and have caused them to be displaced
- the analysis of the location of the fuel assemblies with displaced fuel plates within the reactor core and of events and maintenance that may have caused the displacement
- analysis of vibrations in the fuel assemblies
- ANSTO's inspection regime for the fuel assemblies.

3.4 ANSTO Responses

In its response of 28 March, ANSTO stated:

> *In summary:*
> - *no evidence of abnormal vibration has been found;*
> - *the core-flow distribution has been retested, and there is no significant change in that distribution since Stage A commissioning;*
> - *detailed analysis of the operating records show no unusual events during cycles 4 and 5;*
> - *the fact that relatively few plates moved suggests that there was no gross disturbance during the cycle;*
> - *the displaced fuel plates show no visual indications of damage or deformation; and*
> - *there are no indications of damage or deformation to other reactor core structures and components.*
>
> *The only identified force capable of displacing fuel plates is the drag force from coolant flow. Differential thermal expansion between the fuel plates and side plates produces a stress in the swaged joints. Additionally, normal vibrations present in the core contribute to a reduction in the restraining force within the joint. These two processes, combined with inadequate strength of the swaged joints between some fuel plates and side plates, leads to small relative movement along the joints. Once relative movement within the joint occurs, then the plates begin to displace under the influence of the drag force.*

ANSTO also stated that it had assessed relevant theoretical and experimental evidence and concluded that the major concern of Mr Horoschun with regard to critical velocity 'is not substantiated'. ANSTO provided a document that addressed the hydrodynamic stability of flat fuel plates of the type used in the OPAL fuel design and argued that it demonstrated that, at the flow velocities encountered in the reactor, there is considerable margin to the situation of hydrodynamic instabilities. ANSTO relied upon tests in the flow loop at high flow rates that showed no damage to dummy fuel assemblies and that indicated that the critical velocity is not being approached. ARPANSA arranged for Mr Horoschun to review ANSTO's response and the supporting paper. His response is discussed below.

In response to my questions, ANSTO provided an analysis of the displaced fuel plates and any correlation with coolant flow, primary coolant system pump combination, fuel location, number of cycles in the reactor, plate power and temperature, fuel type, fuel orientation and fuel assembly sequence. ANSTO responded that only ‘standard’ fuel assemblies were affected. ANSTO observed that the fact that there were no displacements from fuel assemblies in the central parts of the core may arise from the fact that these locations only contained non-standard assemblies during the relevant period. No other correlations appear obvious, though later numbered fuel assemblies have the worse faults. The primary pumps B and C were in operation during cycle 5 compared with cycles 1-4 when pumps A and B operated, but there was no indication of any difference in coolant flows and pressures as a result.

ANSTO also provided further analysis of all events that occurred in cycles 4 and 5 and of maintenance activities. None of this analysis revealed any particular cause that could have contributed to the plate displacement.

3.5 Assessment of the cause of the event

Having reviewed the evidence, I conclude that the displacement of the fuel plates from the OPAL reactor fuel assemblies was a result of a combination of causes.

I find that there was a design flaw in the fuel assembly in that there was no secondary stopper mechanism to prevent movement if a primary barrier (swaging) failed.

I also find, based on the evidence presented in the ANSTO submission, that the swaging of the fuel that had been used in the reactor up to and including cycle 5 was inconsistent and did not have the strength expected of it.

These findings are consistent with the preliminary view that I expressed to ANSTO on 15 February 2008.

The final matter in relation to root causes of the event that arises for consideration is whether or not there was some abnormal operation of the reactor during cycle 5 (and cycle 4) that triggered the event or whether it was a combination of design flaws, inadequate swaging and the **normal** operation of the reactor (emphasis added).

ARPANSA expert, Mr Horoschun, raised issues related to the potential for the OPAL flow to be close to the critical velocity leading to significant instability. He reported after evaluating ANSTO’s response that ANSTO had satisfied him that the vibrations of concern are ‘extremely unlikely to be significant.’ His discussion of the issues surrounding this matter satisfy me that there should be no fundamental concern about flow induced instability in properly manufactured OPAL fuel (including the operation of the leading-edge comb included in the fuel design). His discussions also lead me to emphasise the continuing importance of effective swaging for safe operation of the fuel assemblies. Continued testing of the swaging during the manufacturing process is essential.

ANSTO presented an extensive examination of the performance of the reactor over the 5 cycles, with particular emphasis on cycles 4 and 5 in which plates were displaced. This examination identified no evidence of any abnormal forces operating that would have caused the fuel plate displacements. The evidence presented by ANSTO of the vibrational forces within the core and operating on the fuel plates was indirect, in that they did not carry out in-core measurements in OPAL, but does not indicate that these forces were likely to be damaging to the fuel. ANSTO submitted that the most likely conclusion was that the normal vibrational forces and differential heating caused the joint between the fuel plate and side-plate to be weakened sufficiently to allow the known drag forces to displace the fuel plates.

Given the data available from the time preceding the incident, further review effort is unlikely to provide further explanation. Whilst ANSTO did not make direct measurements of the vibrational forces acting upon the fuel plates within the OPAL core, it has set out the reasons why this was not done. I accept the broad validity of those reasons and the questions that they would raise over the value of any data obtained. I also accept that the measurements of vibrations, taken on the dummy fuel assembly in the flow loop in Argentina, are reasonably indicative of the status of the operating environment of the fuel in OPAL.

The obvious question is 'why cycle 5?' It is the case that the largest movements occurred in two fuel assemblies loaded for the first time in cycle 5 and it may be that these were particularly deficient in the effectiveness of the swaging. But other plates did move, and there is the evidence of movement in cycle 4. So there is no simple answer to that question. But, ANSTO has carried out, a thorough examination of the operation of the reactor including undertaking additional testing after questions on these issues were raised by ARPANSA. There is no identified anomaly in this operation that would be a causal factor for the movement of the plates. Consequently, I find that the drag force is sufficient to displace the plates if the swaging is ineffective and that there is no evidence of abnormal operation of the reactor.

While it would have been desirable, if it were possible, to have direct measurements of the vibrational forces acting on the fuel plates during the operation of OPAL, the evidence from the direct measurements that have been done in other parts of the reactor circuit, when combined with the measurements undertaken in the flow loop, do not suggest that there were destructive forces operating in OPAL.

Taking all these matters into account, therefore, I am satisfied that allowing the reactor to operate again (with the modified fuel assemblies) does not present an unacceptable risk to the health and safety of people and to the environment.

Nonetheless, in view of the anticipated reactor operating life of (say) 40 years, I believe it would be appropriate for ANSTO to further develop its understanding of the vibrational forces acting on the fuel plates in the fuel assemblies within the reactor core. To this end, I am proposing an additional licence condition on the facility licence for OPAL that will require ANSTO to develop and implement a work program to address these issues.

4. The Proposed Modification to the Design of the Fuel Assemblies

4.1 Description

ANSTO is seeking my approval to modify the design of the OPAL reactor fuel assemblies according to a design that incorporates two aluminium stoppers screwed with two peened screws to the side plates of the fuel assemblies and positioned with the handling pin of the fuel assembly.

Further, ANSTO proposes that the modified design of the fuel assemblies would be manufactured by the French fuel company CERCA consistent with CERCA processes and quality management of their swaging process.

ANSTO stated that the design bases for the proposed modification are:

- to prevent vertical movement of 19 internal fuel plates greater than 3.5 mm without endangering the integrity of the fuel cladding;
- to ensure that there are no adverse effects on the structural, thermal-hydraulic, neutronic safety or performance of the fuel assemblies or any other part of the reactor; and
- to allow the modification to be made to existing un-irradiated fuel assemblies manufactured by CERCA.

4.2 ANSTO's submission on the design of the modified fuel

In its submission ANSTO described the specification of the stopper and the fixing screws and its method of installation. ANSTO provided:

- a stress analysis of the stopper plate with a bounding assessment based upon the scenario of the impact of all 19 inner fuel plates on a single stopper plate supported by a single screw
- a neutronic assessment that demonstrated only a small 'reactivity worth' for a fuel plate displaced by 3.5 mm that would be allowed by the stopper.
- a thermal hydraulic assessment that examined the effects of the stoppers on coolant flow and the pressure drop across the core. This identified that there may be a small change in pressure drop – this will need to be measured when the reactor is returned to power as the pressure drop is a trip parameter for the first shutdown system
- an analysis of the coolant flow effects of plates being displaced by the maximum amounts allowed by the stoppers.

The ANSTO submission also discussed the stoppers and how they might affect fuel handling and final fuel disposition and submitted that there was no significant impact.

ANSTO reported the results of tests to a modified dummy fuel assembly (using natural uranium in place of the fuel meat) carried out in the flow loop in Argentina. This fuel assembly was constructed with 7 fuel plates being fully swaged; 2 fuel plates with swaging above the fuel plate only; and 12 unswaged plates. The tests, carried out with a flow rate of 116% of the normal OPAL flow rate for periods of 10 hours, then 230 hours and 33 days, showed that the stoppers successfully prevented further movement of the unswaged fuel plates, which were displaced as expected.

Measurements of vibration of the dummy fuel assembly were undertaken and did not reveal any unexpected pattern.

Finally, the ANSTO submission provided a 'failure modes and effects' analysis of the stopper plates and screws during normal and abnormal operations.

ANSTO provided me with its specification for the fuel assemblies to be manufactured by CERCA to the modified design. As part of its overall submission, ANSTO described the fuel swaging processes and testing procedures adopted by CERCA and submitted that these would produce a more reliably swaged joint between the fuel plates and side-plates.

ANSTO also advised that:

- its fuel inspection regime will be improved
- all future fuel assemblies manufactured for use in OPAL will have detailed inspections undertaken by ANSTO at the point of manufacture. The process to be used for this inspection will be consistent with inspection methods currently used by a well established research reactor using similar fuel, HFR-Petten
- the OPAL fuel specification will be modified so that individual fuel plate pull tests are conducted similar to those conducted for HFR-Petten. For the OPAL tests, 7 of the 21 plates in a test sample will be pulled from the side-frame in the lateral direction to determine those individual fuel plates swaging strength

ANSTO provided a statement of the conclusions of its international advisory committee that it had commissioned to review the proposed modification to the fuel assembly. The conclusions of the advisory committee with respect to the design of the stopper were that:

- *The proposed stopper is considered to be a solution to prevent fuel plates' displacement;*
- *The postulated failure of the stopper needs to be assessed in view of the existing SAR and PSA;*
- *The stopper is positioned 3.5 mm above fuel plates;*
- *The stopper is mounted with two screws (4 mm length); tack welding could be considered as an additional securing method;*
- *Reducing width of the empty side plate slot beyond the end of the fuel plates should be considered ("secondary stopper");*
- *Some of the alternative designs of the stopper (pins, combs, etc.) will influence the results and validity of hydraulic testing already performed;*
- *If needed, these alternatives can be considered in due time;*
- *Modifying the side plate slots might be the long term solution.*

4.3 ARPANSA questions

In my letter of 15 February 2008 to ANSTO, I said that the second major issue that needed to be clarified was effectiveness of the proposed design of the stopper and the manufacture, quality assurance and inspection of the fuel. I forwarded some 22 questions relating to the design to modify the fuel assembly and 9 questions on manufacture, quality assurance and inspection.

Issues covered in the questions included:

- the validity of the comparisons between the flow loop tests carried out on dummy fuel assemblies with natural uranium meat and flow tests using the aluminium dummy fuel assemblies used in OPAL commissioning on the one hand and the flow for real OPAL fuel on the other
- the stress analysis calculations for the stopper screws
- the effectiveness of the peening operations used to secure the stopper screws
- the analysis of the hydraulic and dynamic forces acting on the stoppers and screws
- the rigour and extent of the flow loop testing of the fuel with the modified design
- the stopper screw design
- the process for mechanical testing of swaged joints in the lateral and longitudinal direction
- the process proposed by ANSTO for enhanced end-of-cycle inspections of fuel

4.4 ANSTO responses

In its responses of 26 and 28 March 2008, ANSTO stated that it had carried out a number of further tests to support its submission on the structural integrity of the stoppers and screws.

It stated that:

> *The conclusions of the tests and further information from manufacturers confirm that:*
>
> - *the screws that attach the stopper plate to the FA side plate are able to fulfil this function under all normal operational conditions. A number of M6x9 slotted-head screws were tested to determine the failure load under simulated and in-service installation conditions. The failure torque was measured to be approximately twice the installation/service torque;*
> - *the stopper plates are able, individually, to withstand the loads imposed by the impact of all 19 fuel plates without plastic deformation;*
> - *the stopper plates are able, individually, to withstand the loads imposed by the fuel plates caused by fluid drag and hydraulic loads imposed on them by the coolant flow, without plastic deformation;*
> - *peening of the screws increases the torque required to loosen those screws and provides continuing resistance to rotation;*
> - *calculations show that fatigue is not likely to occur in the stopper plates or the attachment screws, even if they were to become loose; and*

- *although the screws do not comply with all the requirements of AS/NZS 1427, the differences have no effect on the ability of the screws to perform their intended function.*

The further ANSTO submission was centred on a report from ANSTO's Institute of Materials Engineering. This report provided a static and dynamic analysis of the stopper plate screws, tests of the effectiveness of peening and an analysis of the structural integrity of the stopper plates. ANSTO submitted calculations showing that the stresses in the stopper screws arising from the force exerted by 19 fuel plates were well within the yield-strength of the screws. A physical test was also carried out that directly simulated the impact of the side-plate being simultaneously struck by 19 fuel plates moving under the drag force of the flow. ANSTO submitted that the examination of the stopper plates after this test showed that no permanent plastic deformation was caused by this impact.

With regard to manufacturing, inspection and quality assurance issues, ANSTO supplied additional information on the CERCA roll swaging process.

ANSTO submitted that it had confidence in the CERCA roll swaging on the following grounds:

- *it uses a computer controlled and repeatable process*
- *……………………………………………*
- *the process is supported by a parametric study of key roll-swaging parameters*
- *CERCA is an industrial facility with an output of 350 elements per year and has experience with numerous complex fuel designs that operate under onerous conditions including FRM II and ILL.*

ANSTO further described the longitudinal pull test that had been carried out on a CERCA fuel assembly that indicated that the longitudinal strength of the CERCA swaging was consistent with its strength in the lateral direction and well in exceedance of the longitudinal strength measured for the CNEA fuel. Subsequently, ANSTO provided the results of another four tests of the longitudinal strength of CERCA fuel, which showed similarly satisfactory results. It did not propose ongoing longitudinal testing as a routine on the grounds of advice from fuel manufacturers that standardised longitudinal tests and criteria are neither established nor accepted internationally.

4.5 Assessment of design and manufacturing issues

While not explicitly stated in its original submission, the subsequent ANSTO responses have made it clear that it is relying upon:

- the swaging undertaken by CERCA as being the primary barrier to upwards movement of the fuel plates
- the stopper mechanism as being an effective secondary barrier to movement.

With regard to the reliance on swaging as a primary defence, I am aware that there is no internationally accepted longitudinal strength testing procedure. Before swaging could be given credit as a primary mechanism for preventing movement of the fuel plates, there needs to be measurement of the effectiveness of such swaging. The results of tests carried out on CERCA fuel to date satisfy me that the appropriately swaged fuel is constrained because of that swaging and this gives me confidence in the CERCA fuel already manufactured to the new design. On this basis, I accept that it is appropriate for ANSTO to present swaging as a means of preventing movement, with the stopper being a secondary mechanism. However, if swaging is to be relied upon for the future, a longitudinal strength testing program needs to be continued and I propose to make a licence condition to this effect. I accept that there is no internationally established longitudinal strength test – but the tests that have been carried by CERCA seem thorough and effective. I propose that the acceptance criterion remain at the value of 27 N/mm that had been applied in the original safety case for OPAL.

With regard to the effectiveness of the stopper mechanism as proposed, a large number of ARPANSA questions strongly tested the design and challenged its effectiveness in the process of questioning. ANSTO responded by carrying out a good deal of additional testing and analysis. I accept that the results of the analyses satisfactorily address the issues surrounding the effectiveness of peening of the stopper screws. I also accept the calculations and testing of the stresses in the screws which shows that they remain within their yield strength under the impact of 19 fuel plates and the mechanical tests of the stopper plates showing no plastic deformation when struck by an equivalent force.

Having said that, it is likely that the design of the OPAL fuel could be improved, if addressed from first principles, without the constraint of needing to be able to modify existing fuel. This is particularly the case in the light of further knowledge of the vibration patterns affecting the fuel plates and knowledge of the effectiveness of swaging that will be accumulated over the next years. I propose to make it a licence condition that ANSTO review the design of the fuel within two years of this decision.

In the light of the fuel displacement having occurred, the possibility of ejection of fuel plates from the core needs to be analysed in the OPAL safety analysis report (SAR). This is common ground with ANSTO and needs to take place in the context of the revision of the SAR required by the operating licence.

5. Safety Management Issues

5.1 Description

I have accepted that a fundamental basis for the displacement event was a flaw in the design of the OPAL fuel assemblies that allowed the fuel plates to move vertically without a secondary stopper mechanism. As noted in section 3.2 above, the original design did not have this flaw – the grooves for insertion of the fuel plates were at the bottom of the assembly and they stopped above the fuel plates, preventing significant upwards vertical movement. During the finalisation of the design, the side-plates were inverted to allow for strengthened attachment of the fuel assemblies to the clamps which attach them to the coolant inlet.

The examination of the sequence of events shows that the designer INVAP did not consider the implications of the design change; it was not drawn to ANSTO's attention specifically, nor did ANSTO reviewers pick up on it as having any significance. This was also the case for ARPANSA review of the fuel assembly design during the process of giving approval to construct items important for safety under the facility licence that authorised construction of the OPAL reactor.

The issue is whether the oversight in the design review process for the fuel assemblies has any significant implications for the design review of the other OPAL systems, structures and components that are important for nuclear safety.

5.2 ANSTO's submission about safety management issues

In its submission, ANSTO acknowledged the 'less than adequate design review' in this case. It stated that:

> *A risk assessment such as an FMEA was not conducted for the fuel assembly, as the established rules for such an analysis during the design phase of the RRR project indicated that FMEAs should be applied to Safety Category 1 systems and assemblies, not components. The fuel was considered to be a component under this system.*

It listed as one of the 'lessons learned' as a result of the incident:

> *To check that no other nuclear safety significant items require risk assessments a review of Safety Category 1 structures, systems and components will be undertaken as part of the safety case update program to identify if any items previously classified as passive components may in fact be considered assemblies of components.*

ANSTO subsequently submitted a document (OSR-010 dated 16 January 2008) that included a table of all the Safety Category 1 systems, structures and components and the risk assessments that had been performed. The document stated that all such structures, systems and components had been subject to a Failure Mode and Effect Analysis except in a small number of cases where ANSTO relied on other types of risk assessments associated with the particular structure, system or component.

The root cause analysis included with ANSTO's submission discussed the circumstances leading to the design oversight. Factors that it brought forward included that:

- Reputable fuel manufacturers accepted the design for tendering purposes without questioning it
- Roll swaging has had a long record of success in research reactor fuel
- It was assumed, in the absence of established longitudinal pull-out tests, that the strength of the swaged joints in that direction was the same as that indicated by lateral pull-out tests.

The document concluded:

Therefore it is inferred that whilst less than adequate design review of the FA design and manufacturing process is the root cause of the OPAL fuel fault, it was due to the specific circumstances outlined above. There is no indication of any systemic failure of the extensive design review process deployed in ANSTO for the OPAL Project.

5.3 ARPANSA questions about safety management issues

ARPANSA asked six questions about the safety management implications of the event. The questions addressed the role of ANSTO and INVAP in the review of the modified design for the fuel assemblies in 2002. One ARPANSA question challenged the conclusion of the root cause analysis about the lack of any evidence of systemic failures in the design review process. The question pointed to other matters that had emerged during the commissioning of the reactor being:

- A fire in the starter motor of a diesel generator arising from an inadequate grounding system and inappropriate maintenance surveillance of the generator batteries
- A flaw in the First Reactor Protection System interlocks that meant an operator in certain circumstances could bypass an interlock
- A failure of a diesel generator on a load test and a subsequent failure to start due to failure in the fuel injector
- Leaks in the reflector vessel that resulted in light water mixing with the heavy water in the reflector vessel.

5.4 ANSTO response to questions

ANSTO again acknowledged that its design review process for the fuel had not been effective. It pointed to a focus on the issue of strengthening of the fuel-plate to end-box stability and the mindset that the swaging provided an effective means of avoiding any upwards movement of the fuel plates. It reiterated its position that it could find no evidence of a systemic failure in the design review process. For each of the events cited in the ARPANSA question, ANSTO responded that there had been different root causes, none were related to flaws in design review, being deficiencies in manufacture, installation or maintenance and a software error in one instance.

ANSTO submitted:

The conduct of a design review process does not always prevent component failures, although it is a major objective. In any complex engineering system, it is recognised that there will be some 'teething' troubles, which will be identified in its early life, particularly during commissioning, despite design reviews and quality assurance measures.

5.5 Assessment of safety management issues

Having assessed the evidence, I conclude that the design review oversight that did not assess the implications of the change of design that resulted in the side-plate grooves being at the top of the fuel assembly flowed from a mind-set of the reviewers that swaging was accepted as a barrier of more than adequate strength to prevent upwards movement of the fuel plates. Thus, the design change was not thought to be of significance and not brought to attention as an issue with significant implications for safety by INVAP to ANSTO and in turn by ANSTO to ARPANSA. This resulted in the design change not being the subject of detailed scrutiny by any of these parties.

The ARPANSA reviewers, not having their attention drawn to this matter, focussed on other issues about the fuel.

I accept ANSTO's view that the several issues that have arisen during the OPAL commissioning are not necessarily of themselves indicative of flaws in the design review process overall. Each has a somewhat different cause and it is the purpose of a commissioning and early operating period to ensure that early problems are detected and addressed.

The design and manufacture of fuel for research reactors is very specialised and expert knowledge of fuel design issues is not widespread in the research reactor community. Certainly the OPAL fuel has now been thoroughly tested and the work program that I propose to include as a new licence condition on the OPAL facility licence will further develop the knowledge of the performance of the fuel in its operating environment..

6. OPAL recommencement of operation with the modified fuel

6.1 OPAL return to service

Once the modified design of fuel is approved by me ANSTO has advised that that they wish to then return the reactor to service. I have been provided with a return to service plan by ANSTO.

It is ANSTO's submission that:

- this return to service plan is already contemplated by the scope of the authorisation given under the facility licence that authorises operation of the reactor.

- the Return to Service Program (RTS) does not involve a revision or a replacement of an evaluation methodology used in the SAR. It is stated that the test instructions are based on commissioning procedures as used during stage B1, B2 and C Commissioning Stages.

- there are no activities or tests that are to be performed that have not already been considered in the SAR or Commissioning Safety Case.

- the RTS program does not involve any change to the SAR, operational limits and conditions (OLCs), plans and arrangements for managing safety or plant procedures.

Based on the documents that I was provided with prior to making this decision, I am confident that I may allow the modified fuel to be loaded into the reactor and appropriate tests to be carried out for the completion of that stage.

I wish then for my regulatory inspectors to provide me with a report on the outcome of fuel loading. Whilst these activities are being undertaken I will review the remaining steps that are proposed in the RTS Program.

In summary ANSTO may:

- perform all activities associated with verification and surveillance of the OLCs undertaken in shutdown conditions.

- remove the 16 new fuel assemblies from the fresh fuel vault, inspect them in accordance with new instructions specifically developed for this purpose and load the fuel assemblies into the reactor pool storage rack.

- perform testing, including the measurement of core differential pressure with 16 fuel assemblies loaded into the core and with the reactor shutdown and for different primary coolant pumps configuration.

- undertake other preparatory testing and verification.

- transfer fuel assemblies from the storage rack to the core. This would correspond to the loading of the 12 first fuel assemblies. My approval would be required before undertaking the approach to criticality.

6.2 Scope of the authorisation

The key issue in relation to the scope of the authorisation is whether the return to service of the OPAL reactor is contemplated by the existing authorisation. As previously discussed this authorisation defines operation as being comprised of hot commissioning and then routine operation. At the time of the fuel displacement event the OPAL reactor had completed Stage C commissioning and had submitted a Stage C Commissioning report to me for my consideration. As at 26 July 2007 there were some outstanding issues that I wished ANSTO to address in the context of the Stage C commissioning report. These matters are still outstanding.

I characterise the return to service as a continuation of the hot commissioning program, particularly as the return to service requires a “start up” core. The tests and procedures that will define this stage are drawn from the commissioning tests and procedures and are clearly defined by ANSTO in its submissions as part of the commissioning stage. I am satisfied that it is within the existing envelope of the authorisation as I defined it when I issued the facility licence on 14 July 2006 and I therefore do not intend to amend the scope of the existing authorisation. I will deal with the staged return to service under the existing authorisation.

John Loy
CEO of ARPANSA
1 May 2008

Appendix 1

Summary Findings of Report from Mr Jim Snelgrove

Mr Snelgrove had worked for many years at the Argonne National Laboratories in the US on a program to produce reduced enrichment fuel for research reactors. He reviewed ANSTO's submission and reported in summary as follows:

> *On the basis of my review of all documents reviewed:*
> - *I find the ANSTO/INVAP investigations of the fuel-plate-movement events to be comprehensive, well-planned, well-executed, and well-documented.*
> - *With the exception of the few errors noted in Section 3, I found the information presented in all of these documents to be accurate.*
> - *I concur with the finding that a lack of adequate swaging and of a "stopper" allowed the plates to move. I emphasize, however, that the underlying causes were the lack of an adequate design and a less than adequate review of the FA design and manufacturing process.*
> - *I concur with the proposed remedy of adding a stopper plate to each element side plate; this remedy has been verified to work both by analysis and experiment. In fact, the addition of the stopper plates slightly decreased the hydraulic resistance of the fuel element.*
> - *The fuel element specifications presented contain all necessary information and are in accord with international best practice.*
> - *I found no unresolved potential safety issues.*
> - *In my opinion, ARPANSA would be justified to approve continued operation of OPAL using the proposed modified fuel elements, based upon the documentation that I reviewed.*

ANSTO has undertaken to correct the errors identified by Mr Snelgrove in its documentation.

Appendix 2

Comments from Nuclear Safety Committee members

Following circulation of the ANSTO responses to questions out of session to NSC members with a request for any comments, I received the following from Dr Peter Johnston:

> *I have examined the responses from ANSTO of March 2008 and these have satisfied me that they have undertaken reasonable and appropriate studies and reached sound conclusions.*
>
> *In particular:*
> *1. Root Cause Analysis (RCA)*
> *The RCA has 3 elements (i) no stopper (design flaw), (ii) swaging failure, and (iii) the fault occurred during routine operation.*
> *(i) The design flaw is clear and acknowledged.*
> *(ii) The deficiencies with CERCA swaging have been clearly demonstrated.*
> *(iii) To prove a nil result about abnormal occurrences is not possible, but the documentation indicates a clear search of appropriate areas has been conducted without finding a cause in an abnormal occurrence. I conclude the RCA is sound.*
>
> *2. Is the proposed new stopper and new CERCA fuel adequate?*
> *I believe the documentation about the adequacy of the stopper design, screws and possible deflection convincing. I am also convinced that the quality of CERCA swaging is superior to that of the original CNEA fuel and adequate.*
>
> *3. Is there evidence of systematic design failures in faults observed to date?*
> *No. There has been a good account of the nature of observed faults during commissioning and an underlying systematic trend is not evident. Research reactors such as OPAL are individually designed and therefore could be considered prototypes. Commissioning should bring forward faults as has occurred.*
>
> *4. Why did the fault occur in cycle 5 and not previously?*
> *There is some evidence of minor plate movement in Cycle 4. Further analysis of FAs and plate numbers has not identified why cycle 5 was the cycle of failure. I cannot see any point in pursuing this point further.*
>
> *5. Vibration Issues*
> *ANSTO have provided valid reasons why further testing using accelerometers closer to FPs was not undertaken. I also find the arguments presented to be satisfactory with respect to critical velocity and vibration. The examination of irradiated plates, lack of wear marks as well as testing of dummy FAs provides evidence that vibration concerns are not substantiated.*

6. ANSTO Safety Management
ANSTO has explained in more detail the process of internal committees dealing with the safety submission. The quality of documentation provided to support submission E0083 is much superior to that provided on previous occasions. The time taken by ANSTO in internal reviews and their extent indicate an improvement in safety culture and respect for regulatory process. While improving safety culture is an ongoing process, I view these improvements positively.

General Conclusion
I have no further questions about submission E0083 and I am happy to see it approved. I believe the state of the reactor following extended shutdown to be a separate matter.

Mr Neil McDonald and Professor Ian Polmear supported this general conclusion, though Professor Polmear would have preferred that the stopper be secured by rivets or by spot welds at an edge of the screws.