SITE GEOLOGICAL INVESTIGATIONS FOR THE REPLACEMENT RESEARCH REACTOR AT LUCAS HEIGHTS
ASSESSMENT BY THE CEO OF ARPANSA

Introduction

On 4 April 2002, I issued a facility licence ('the construction licence') under section 32 of the *Australian Radiation Protection and Nuclear Safety Act 1998* (ARPANS Act) to the Australian Nuclear Science and Technology Organisation (ANSTO) to construct the Replacement Research Reactor (RRR) at Lucas Heights.

As discussed later in this document, one of the issues relevant to my decision to issue the construction licence was the seismic design basis for the RRR. In considering whether to issue the construction licence, I required ANSTO to carry out further geological studies near the site. The studies were to determine if there were any faults that had the potential to cause surface displacements at or near the site. The results of these near field studies were available to me in January 2002 and did not indicate that there were any such faults in the vicinity or tending towards the site.

Prior to my issuing the licence, I had also asked ANSTO to undertake studies to examine any faulting in the excavation site itself, by way of confirmation of the earlier near field information. The studies undertaken during June 2002, showed that there was faulting on the reactor site and ANSTO subsequently examined this faulting and submitted a report to me.

The purpose of this review is to consider the ANSTO submission and to assess ANSTO's characterisation of the faulting and whether it changes my understanding of the seismic hazard analysis for the facility, which I relied on when I made my decision in April 2002 to issue the construction licence.

In making this assessment, I have examined the following documents:

<u>ANSTO SUBMISSION</u>

- *Submission to ARPANSA on the Site Geological Investigations for the Replacement Research Reactor at Lucas Heights*, ANSTO, RRRP-7500-3BEAN-002-A ,

- *Additional Geological Investigations Undertaken in Support of the Replacement Research Reactor at Lucas Heights,* ANSTO, RRRP-7500-3BEAN-A, which includes ten attached reports supporting the main submission

- *ANSTO – Replacement Research Reactor Project – Tasks 1 and 2 – Site Fault Assessment,* Institute of Geological and Nuclear Sciences, client report 2002/103, providing a report on the earlier near field study and the detailed description of the RRR site faulting

ARPANSA REVIEW OF ANSTO SUBMISSION

- *ARPANSA Review of the Submission on the Site Geological Investigations for the Replacement Research Reactor at Lucas Heights,* ARPANSA Regulatory Branch, 21 October 2002. This review includes reports by experts engaged by ARPANSA:

    - *Review of the Assessment of Surface Faulting at the RRR Site, Lucas Heights, Australia,* Dr Leonello Serva, organized by Division of Nuclear Installation Safety, International Atomic Energy Agency (IAEA)
    - *Initial Review of Submission to ARPANSA on Site Geological Investigations of Lucas Heights: Questions and Clarifications Requested,* Geoscience Australia, 24 September 2002; *Response to Consideration by Geoscience Australia of ANSTO Submission to ARPANSA on Site Geological Investigation of Lucas Heights,* ANSTO; *Comments on response of ANSTO to issues Raised by Geoscience Australia,* Geoscience Australia, 17 October 2002.

I re-examined the following documents:

- The Reasons for Decision that accompanied my licence decision on 4 April 2002

- The Regulatory Branch Assessment Report (RB-ASR-09-02) that set out the ARPANSA Regulatory Branch assessment of the ANSTO facility licence application.

I did not seek formal advice from the Nuclear Safety Committee, but ANSTO did provide a detailed briefing and a site visit for the Committee. This is described on the ARPANSA website at www.arpansa.gov.au.

The questions that I have addressed

These circumstances that have arisen are not unique to the RRR. A document from the US Nuclear Regulatory Commission[1] states:

> *'During the construction of nuclear power plants licensed in the past two decades, previously unknown faults were often discovered in site excavations. Before issuance of the operating licence, it was necessary to demonstrate that the faults in the excavation posed no hazard to the facility. - - - - - -, these kinds of features should be mapped and assessed as to their rupture and ground motion generating potential while the excavation's walls and bases are exposed'.*

A seismic event is an external hazard with the potential to disrupt the independent safety systems protecting a reactor. Hence, assessment of the seismic design of the Replacement Research Reactor was an important issue during my assessment of the application for the construction licence. It is described in my Reasons for Decision at Part Five, in the ARPANSA Regulatory Branch Assessment Report (RB-ASR-09-02) at

[1] U.S. Nuclear Regulatory Commission, REGULATORY GUIDE 1.165 – Identification and Characterization of Seismic Sources and Determination of Safe Shutdown Earthquake Ground Motion, March 1997.

3.2.9, and in a report to me by the Nuclear Safety Committee that I addressed in Part Twelve of the Reasons for Decision. The seismic issues earlier were addressed by the IAEA peer review of the Preliminary Safety Analysis Report (PSAR) and an international expert obtained through the IAEA also assisted ARPANSA.

A major part of the assessment was the determination of the design basis seismic hazard at the site through a probabilistic seismic hazard analysis that was carried out by the New Zealand Institute for Geological and Nuclear Sciences (GNS). This analysis resulted in a spectrum for the vibrations at the site produced by earthquakes with a return period of 10,000 years. A more conservative version of this vibrational spectrum was then used by ANSTO as the design basis for critical systems, structures and components of the reactor. I assessed that the seismic design proposed in the application by ANSTO on the basis of this design basis hazard was satisfactory, having regard to international best practice in radiation protection and nuclear safety.

The seismic design basis is a spectrum of ground vibrations that is then applied to the building and the systems, structures and components of the Replacement Research Reactor. There is no assessment against surface displacement. In this regard, I note that the IAEA safety guide on seismic hazard evaluation for nuclear power plants states that:

> *'In the site evaluation for a plant, engineering solutions will generally be available to mitigate, by means of certain design features, the potential vibratory effects of earthquakes. However, such solutions cannot always be demonstrated to be adequate for mitigation of the effects of phenomena of permanent ground displacement such as surface faulting, subsidence, ground collapse or fault creep'.*

The seismic hazard analysis that was carried out by GNS required knowledge of, and probabilistic assumptions about, the sources of seismicity that could affect the site. A series of zones were delineated around the Sydney area with the seismicity of each zone postulated on the basis of seismic records. The Lapstone structural complex was identified as a specific seismogenic source assumed to have an 80% chance of being active.

The determination that I must make is whether the discovery and characterisation of faulting on the site subsequent to the issuing of the construction licence changes one of the factors (seismicity) that informed my decision to issue a construction licence. In particular:

- Is there a possibility that the faulting at the site may move in an earthquake and cause surface displacement? In seismological terminology a fault that can cause surface displacement is called 'capable' – is the faulting on the site capable?

- Do the further geological investigations indicate that the basis for the seismic hazard analysis, relating to the seismic design basis of the reactor, that informed my decision of 4 April 2002 needs to be revised substantially?

The evidence

Description of the faulting

The ANSTO submission, including the supporting reports by ANSTO's consultants, describe the faulting on the site in great detail.

In simple terms, a fault is a fracture in rocks of the earth's crust, where compression or tension forces cause the rocks on the opposite sides of the fracture to be displaced relative to each other. A 'normal' fault is caused by horizontal tension forces and a 'reverse' fault by compression forces when the earth's crust is shortening in the geological region concerned. The geological term 'fault' covers a great extent of features – faults range in length from a few centimetres to many hundred kilometres and displacements across faults may range from less than a centimetre to kilometres.

ANSTO submit that there are two main fault strands on the site. Both fault strands cross the reactor excavation in a NNE direction and dip steeply. The eastern strand is an apparent normal fault and has displacements in the rock strata of 1 to 1.3 metres. The western strand has an apparent displacement in the opposite direction to the normal fault and displacements of 0.2 to 0.3 metres in the sandstone and mudstone beds. The eastern strand fault extends for at least 140 metres across the site while the western strand extends for at least 120 metres across the site. The two main faults converge in the northern part of the site to form a single fault zone and form a complex zone of faulting and fracturing.

In detail, when viewed on the reactor walls and at different trenches across the site, the fault strands are quite complex. For example, the eastern fault strand breaks up into three main strands in the floor of the reactor excavation and these are mapped on the north wall of that excavation. They then merge to the north only to bifurcate again towards the limit of the mapping undertaken.

The faulting has been examined in most detail in the reactor excavation and in a trench that was dug to the north outside the site fencing (Trench 4). There have been no questions raised by either ANSTO consultants or the ARPANSA assessors about the accuracy of the mapping carried out by GNS of faulting seen in the excavation and the different trenches.

Regional geology

The ANSTO submission puts faulting on the site in the context of the regional geology of the Sydney Basin. It states that detailed analysis of faults from the Southern Coalfield (south of the RRR site), and from tunnels excavated within Hawkesbury Sandstone (north of the site), indicate normal fault displacements on two main sets, which strike north-west and north to north-east. The faulting on the RRR site belongs to the north north-east set. The tunnelling and excavation information indicates that normal faults are seen on average every 140 metres and reverse faults every 1 to 3 km and the faults generally have small displacements.

The ANSTO submission argues that the Tasman Sea rifting that occurred around 50-80 million years ago was the largest tectonic event to affect the region after the deposition of the Hawkesbury Sandstone. It is regarded as the most likely cause of the normal faulting in the Sydney Basin. The reverse faulting seen in the western fault on the site is interpreted as arising from later re-activation – though some of the experts consulted are of the view that it is a part of an otherwise normal fault that is reversed in a small zone because of local factors and probably occurred during the Tasman Sea rifting.

The age of the faulting at the site

An important part of assessing whether a fault is 'capable', that is, whether it has a significant potential for relative displacement at or near the ground surface is whether it shows evidence of movements in the relatively recent (geologically speaking) past.

ANSTO commissioned their consultants to undertake several approaches to constrain the age of movement of the faulting at the site. This is not a straightforward task – there were no methods that could provide a simple, direct measure of the fault age. The approach was to determine the ages of features that were believed to be younger than the last fault movement on the basis of geological principles and site observations. Several such approaches were used.

First, in Trench 4, the faulting, which had been followed from the reactor site, was found to have been overlain by younger, un-faulted sediment. Trench 4 is in a broad gully and it is argued by ANSTO that this covering material is likely to have been deposited in the area and that there may have been successive episodes of deposition and erosion. A direct dating technique was applied to layers of this material that gave ages of 14,000 years in the upper layers down to 104,000 years in the lowest layers (noting that the dating technique becomes 'saturated' at this time and cannot discriminate material older than 104,00 years.)

This evidence is interpreted by ANSTO as indicating that, at the very least, the fault has not moved for 104,000 years.

The second approach used by ANSTO's consultants was to apply paleomagnetic dating to some suitable materials. This technique relies upon iron bearing minerals in rock that are formed at the time of the formation of the rock or through later chemical changes. The minerals retain a 'remanent magnetism' that is aligned with the earth's magnetic field at the time of their formation. It is well established that the earth's magnetic field has been reversed from its current polarity, the last sustained reversal concluding some 780,000 years ago. It is also possible for a paleomagnetic measurement to provide a more refined dating. This is done by comparing the inclination of the remanent magnetism to that which might be expected from knowledge of how the Australian continent has moved in latitude over geological time relative to the magnetic pole ('Australian apparent polar wander').

The most critical paleomagnetic measurements that were undertaken by ANSTO's consultants were those of a sample of a ferruginous (iron bearing) layer that crosses the fault at the southern wall of the reactor excavation. First, the remanent magnetism was found to be reversed (as was the case for other similar samples from Trench 4 and elsewhere) which would argue for an age of greater than 780,000 years. Comparison through the polar wander technique is then relied on by ANSTO to submit a date of 9 ± 4 million years (at the 95% confidence level).

This evidence is interpreted by ANSTO as saying that the fault has not moved for at least 5 million years.

The next approach taken by ANSTO's consultants was to date material taken from boreholes in the site and that exhibited evidence of deep weathering. Another dating technique was applied to do this, relying upon the fissioning of the uranium in the rock and upon the radioactive decay of the uranium and thorium. The interpretation of these results is complex as they are affected by the thermal history of the formations – but the interpretation put forward by ANSTO is that the deep weathering episode provides a constraint upon the last time of significant fault movement in the interval of 10-35 million years ago. The argument that this is so relies upon the occurrence of materials arising from the weathering in localised zones along various fault planes. This requires that the fracture planes of the faults were in existence during the deep weathering process and have not moved since.

ANSTO's assessment of the capability

To assess whether the faulting on the site is capable (of causing displacement at or near the surface), the ANSTO submission applies criteria drawn from the IAEA and the US Nuclear Regulatory Commission.

The first criterion in both the IAEA and NRC documents relates to whether the faulting shows signs of movement in recent geological time – '*within such a period that it is reasonable to infer that further movement at or near the surface can occur*' (IAEA). For the NRC criterion, the timescale defined is '*of a recurring nature within the last, approximately 500,000 years, or at least once in the last, approximately, 50,000 years'.*

ANSTO points to the evidence of the age of the last movement in the faulting described above.

The next criterion (second in the IAEA list and third in the NRC) is that a fault may be capable if it has a structural relationship or structural association with a known capable fault, '*so that movement on one could be reasonably expected to be accompanied by movement on the other'* (NRC, similar wording in IAEA).

ANSTO argues that the nearest known capable fault is the Lapstone structural complex that is located about 35 km west of the site. This distance and the fact that the Lapstone structural complex is located in a separate structural zone are argued to demonstrate that there is no structural relationship or association.

The third criterion – expressed somewhat differently in the IAEA and NRC criteria - relates to association with earthquakes. The IAEA expresses this as that

> *'the maximum potential earthquake associated with a seismogenic structure - - - - - - - is sufficiently large and at such a depth that it is reasonable to infer that - - - movement at or near the surface could occur'.*

The NRC criterion is:

> *'a reasonable association with one or more large earthquakes or sustained earthquake activity that is usually accompanied by significant surface deformation.'*

The ANSTO submission in relation to the IAEA criterion argues that the only seismogenic structure is the Lapstone structural complex, which might be expected to have ruptured many times in the past 5-13 million years and not triggered any slip at the Replacement Research Reactor site. Further, it is not a part of the same geological structure. For the NRC criterion, the ANSTO submission simply states that the site fault has not been associated with a large earthquake or sustained earthquake activity.

My assessment of the evidence

Is the faulting 'capable'

The principal argument presented in the ANSTO submission and supported by the ANSTO consultant studies is directed to the age of the fault, the time since it last moved.

There are no direct measurements of the age of the faulting presented in the ANSTO submission; rather there are measures of the age of other features and arguments made on the basis of knowledge and observation of the local geology that these features post date the latest movement of the faulting.

Practised and capable scientists have carried out the measurements that provide the age of the various features and I accept the expertise of these scientists. I have then focussed my attention on the arguments that seek to establish the relativity between the age of the feature measured and the last movement of the faulting.

The first feature is the unfaulted sediment covering the bedrock in Trench 4. The lowest level of this sediment was dated by optically stimulated luminescence (OSL) as being at least 104,000 years. Geoscience Australia agrees that ' *the most plausible explanation of the evidence provided is that the deposition of the sediments overlying the saprolite in Trench 4 post dated faulting. A minimum age of faulting of >104,000 years is therefore supported, based upon the OSL results.'*[2]. I accept then that this

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[2] Geoscience Australia did question whether the faulting seen in Trench 4 was a direct continuance of the east and west fault strands, since they dip in a different direction. Given the response from ANSTO, Geoscience Australia agree '*that the faults in Trench 4 are likely to be kinematically related, if not directly correlatable, to those exposed in the reactor hall excavation'*.

evidence establishes a limit to the movement of the faulting being at least 104,000 years ago.

There are general geological arguments and some evidence from paleomagnetic data that there have been episodes of deposition and erosion in this lower lying area and that therefore this is a minimum age. This seems plausible, but does not establish any older date.

I then turn to the dating of the ferruginous layer visible in the south wall of the reactor excavation. The remanent magnetism is reversed, giving a date for the chemical weathering involved of greater than 780,000 years ago and the application of the apparent polar wander technique provides a date of 9 ± 4 million years ago.

This is the critical piece of evidence and its significance turns upon how clearly it is established that the weathering and oxidation that created the ferruginous layer took place after the faulting. Geoscience Australia has closely questioned ANSTO and its consultants on this point.

ANSTO in its response to Geoscience questions makes some general geological and observational arguments to support the case. Additional specific evidence is advanced by ANSTO from the paleomagnetic measurements of the samples taken from the area where the ferruginous layer can be seen to dip across the western fault on the south wall of the reactor excavation. The remanence directions from the samples are strongly clustered, despite the varying dip of the beds as they are folded across the fault line. This would be expected if they post dated the fault – had the fault occurred afterwards, it should have resulted in a scattering of the remanence directions.

Geoscience Australia state that this argument provides 'a simple and elegant demonstration' and that the additional data:

> *'provides a compelling case that no additional significant internal rotation of material has occurred - - -*(within the relevant samples*) - - - for at least 9±4 Myr. This in turn suggests that no significant movement has occurred since that time on the fault - - - .'*

In view of the Geoscience Australia analysis after testing of the evidence, I find this measurement of the age of the ferruginous layer, when combined with the strong argument that it post-dated the faulting, to be a convincing demonstration that the faulting is at least 5 million years old.

The final dating evidence is the dating of the deep weathering. The ANSTO submission combines the direct evidence of the age of this episode through the fission-track and U-Th/He dating and geological argument that it post dated the faulting to give a further constraint upon the age of the faulting as being from 10-35 million years old. Again, Geoscience Australia has challenged the latter arguments about post dating the faulting. Geoscience Australia acknowledge the force of the ANSTO position, but argue that it builds a body of evidence *'that the last fault movement occurred in antiquity, rather than providing independent constraint on the last episode of movement'*. This is a much more complex and subtle argument than the case made for the dating through the measurement of the ferruginous layer. While acknowledging that it may well establish an even earlier date for the time of the faulting movement, I have not taken it into account in my assessment of the capability of the faulting as described below.

Turning then to the criteria for assessment of capability, I believe that the IAEA and NRC criteria are similar and reflect international best practice in radiation protection and nuclear safety in this regard.

Taking the first criterion that relates to recent movements, I accept the evidence that the fault has not moved for at least 5 million years. It is notable that the IAEA criterion refers to the differing timescales likely to be required in highly active areas of short earthquake recurrence intervals (where the faulting is 'tested' frequently by earthquakes) from those in less active areas. Australia is tectonically quiet, but Dr Serva in his report states that he regards the minimum of 5 million years as being sufficient to meet the IAEA criterion (and it certainly meets the NRC formulation).

It seems to me that the other two criteria are much more straightforward. There is no evidence of there being any known capable fault in the area, other than the Lapstone structural complex (and even this is debated). Dr Serva notes that this is some 35 km to the west of the site and thus no secondary movement is expected to occur and further that the complex is in a separate tectonic zone and that similar zones do not extend further east towards Lucas Heights. Further, Dr Serva does not see the third IAEA criterion as being relevant to the circumstances of Lucas Heights. I accept the point that ANSTO makes that there is no reasonable association with a large earthquake or sustained earthquake activity.

Does the seismic hazard assessment for the RRR change?

The conclusion reached in the ANSTO submission is an important one:

> *'The geology and fault characteristics of the RRR site are consistent with the general pattern of extensive faulting that persists in the region, a region of low tectonic activity'*

I interpret this conclusion to mean that there is nothing in the discovery of this faulting that has any significant implications for our knowledge of the geology and seismicity of the Sydney Basin.

The seismic hazard analysis, which forms the basis for the seismic design of the RRR, relies on dividing the area surrounding Lucas Heights into zones having similar seismic activity, based upon historical earthquake data. Additionally, the Lapstone structural complex is explicitly modelled using estimates of the likelihood that the complex is an active fault and of its slip rate.

I accept that the characterisation of the faulting passing through the RRR excavations has not found any features that distinguish it from the many hundreds of similar faults throughout the Sydney Basin. These faults are implicitly accounted for in the seismic activity attributed to the Sydney Basin zones in the seismic hazard analysis. There has not been any result from the recent studies that would cause a re-examination of this approach.

The ARPANSA Regulatory Branch has reviewed the recommendations and conclusions that it reached in bringing forward advice to me for the construction licence and confirmed that they remain valid.

Conclusion

I find that the faulting on the site of the RRR is not capable of resulting in surface displacement. The basis for my conclusions about the seismic design of the RRR remains valid.

John Loy
CEO of ARPANSA
21 October 2002