ARP NSA

Australian Radiation Protection and Nuclear Safety Agency

Review of the ANSTO Submission on the Site Geological Investigations for the RRR at Lucas Heights

Regulatory Branch

RB-ASR-48-02

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CONTENTS

1. Background

The ANSTO submission to ARPANSA on investigation of the fault found in the excavations for the replacement research reactor (RRR) (1) identifies many previous assessments of the geology and seismology of the Lucas Heights region. These have been reported in the Environmental Impact Statement (EIS) (2) and Preliminary Safety Analysis Report (PSAR) (3) for the RRR. This information was taken into account by ARPANSA in the Regulatory Branch Assessment Report (RAR) RB-ASR-09-02 of the Application (4) to construct the RRR. In particular section 3.2.9 of the RAR covers seismicity, and covers the seismic design of the reactor structures, components and systems (SSC).

The ARPANSA Regulatory Assessment Principles (5) requires the design and the design bases analysis to address severe earthquakes having a mean return period of up to 10,000 years. Also for beyond design basis accidents, there should be no "cliff edge" effect, that is, a sudden increase in consequences below the frequency band for design basis accidents. The PSAR (3) and ANSTO's Consolidated Seismic Report (6) were reviewed by ARPANSA's Regulatory Branch, and by an IAEA consultant to ARPANSA (7) with the following general observations:

1. The seismic analysis and design procedures used for the RRR meet the international standards for nuclear power facilities, including nuclear power plant.
2. Implementation of the programs described in the PSAR and the Consolidated Seismic Report will lead to a facility with a high level of seismic capacity, including beyond design basis capability.
3. The seismic design ground motion defined by the envelope of the 0.3 g peak ground acceleration US NRC Regulatory Guide 1.60 response spectra with the IGNS 0.37g peak ground acceleration site specific response spectra, is extremely conservative with respect to the spectral shape.
4. In the beyond design basis evaluation for the reactor building, failure was not predicted to occur prior to about two times the design basis earthquake (SSE) equivalent load level.

These review findings are reflected in Finding 3.2.9-1 of RB-ASR-09-02 (4) in respect of the reactor building, structures, systems and components capability to withstand the vibratory accelerations, velocities and displacements associated with the design Response Spectra chosen, as follows:

> *The reviews that have been undertaken by the Regulatory Branch and the IAEA experts contracted by ARPANSA give confidence that the seismic design of the reactor structures, systems, and components important for safety has been very conservative. The margins identified give a high confidence in a low probability of failure for all such structures, systems, and components at least twice those of the design basis earthquake.*

Section 3.2.9 included a recommendation by the IAEA Peer Review Team ((8) June 2001) that an additional study be undertaken for the Lucas Heights site in accordance with IAEA Safety Guide 50-SG-S1 (9). In particular this related to regional and local investigations to determine whether there exists a potential for surface faulting at the site area, to formulate the investigations that should be used to determine whether or not any faults in the area should be considered capable. The CEO of ARPANSA requested ANSTO to undertake such a task.

The sequence of events leading to the discovery of the faulting is shown in the time-line below:

- 10 July 2001 - IAEA peer review (8) undertaken on behalf of ARPANSA and Recommendation 8 for an additional seismic study in line with IAEA 50-SG-S (9).
- 17 September 2001 - Letter to ANSTO - ARPANSA requests ANSTO to undertake a near site investigation of faulting out to 5km and mapping of any site excavations, in line with IAEA Recommendation 8.
- January 2002 - Reporting of IGNS and Coffey Partners (10) near site investigation out to 5 km from the RRR. No evidence found of an active fault.
- April 2002 - CEO of ARPANSA issued the Construction Licence (4) and site excavation work started.
- June 2002 - Fault discovered on site during excavation and work stopped on excavation site to allow investigation of the significance of the fault.
- July to August 2002 - Assessment and mapping of the site and excavations including various trenches in addition to the RRR foundation excavations.
- 12 to 16 August - Site visit and meetings with ANSTO and its consultants by ARPANSA personnel and consultants.
- 12 September 2002 - Issue of the ANSTO submission to CEO of ARPANSA (1) on the site geological investigations for the RRR, including the various reports by ANSTO consultants on additional geological investigations and site fault assessment.
- September 2002 – ANSTO report placed on ARPANSA web site and, together with reports by ANSTO's consultants, sent to local libraries around Lucas Heights.
- 24 September 2002 – Questions and clarifications on ANSTO submission sought by ARPANSA on behalf of its consultant Geoscience Australia.
- 26 September – ARPANSA consultant Geoscience Australia visited Lucas Heights to view fault for discussions with ANSTO and its consultants IGNS.
- 27 September 2002 - ARPANSA's Nuclear Safety Committee visits the site to inspect and discuss the fault and the ANSTO submission on the age and capability of the fault.
- 4 October 2002 – ANSTO's responses to questions of Geoscience Australia.

2. Previous Assessments of the Geology, Geo-physics and Seismology of the Lucas Heights Region

The Submission summarises the previous assessments on the geology and seismology of the region surrounding Lucas Heights. These are:

- A generalised descriptive understanding of the geology (Sherwin and Holmes).
- Geophysical study of the RRR site by Coffey Partners as part of the RRR EIS, which had identified minor dykes.
- A geo-hydrological and hydro-chemical study of the RRR site.
- Near site investigation by Coffey Geoscience to look for surface faulting and further measurements of the acoustic velocity in the soil on the site.
- A Probabilistic Seismic Hazard Analysis (PSHA) (11) known as the Alliance Report, which included a review of the earthquake ground shaking hazard at Lucas Heights. The outcomes from the study included predicted mean peak ground accelerations and response spectral accelerations for a range of return periods.
- An extension to the PSHA by IGNS (12) based on input data derived by consensus of experts on eastern Australian seismicity, which slightly modified the predicted mean peak ground accelerations and response spectral accelerations for a range of return periods.

As outlined in the PSAR (3) and the ANSTO Consolidated Seismic Report (6), the RRR has been designed to withstand, as a minimum, the predicted mean peak ground accelerations and response spectral accelerations for an earthquake return period of 10,000 years.

As stated above, Section 3.2.9 of the ARPANSA review of the PSAR (RB-ASR-09-02) (4) in April 2002, reviewed this seismic design taking into account the IAEA Peer Review (8), an IAEA Consultant report (7) and public submissions. The ARPANSA finding was that that the seismic design of the reactor structures, systems, and components (SSC) important to safety has been very conservative. The margins identified in the PSAR gave a high confidence in a low probability of failure for all such SSC from the vibrations associated with accelerations of at least twice those of the design basis earthquake.

3. Regional Geology of the Sydney Basin (including most importantly fault data in the Sydney Region)

The regional geology for the Sydney Basin is described in detail in the ANSTO submission (1). Of most interest to the current investigation is the information on faulting. The key points are:

- Most faulting activity in the Sydney Basin occurred as a result of the Tasman Sea opening 85-53 million years ago.

- The Lapstone Structural Complex is a prominent tectonic and physiographic feature of the Sydney Basin. The complex is more than 100km long and generally about 2 to 5 km wide and is 35 km west of Lucas Heights. The potential for the LSC being active was considered in the Alliance 1999 report (11) and the IGNS 2001 report (12) Probabilistic Seismic Safety Analyses. Both of which were considered in the Regulatory Branch Assessment Report (RAR) RB-ASR-09-02 (4) of the Application to construct the RRR.
- 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.
- In displacement terms the northwest striking faults are the dominant set and the fault sets on the RRR site belong to the north-northeast set.
- The tunneling and excavation information indicates that normal faults are seen every 140 metres, and reverse faults every 1 to 3 km and the faults generally have small displacements.

The geology and fault characteristics of the RRR site are regarded in the ANSTO submission (1) to be consistent with the general pattern of extensive faulting that persists in the local region, which is generally considered to be a region of low seismicity. The Probabilistic Seismic Hazard Assessment (PSHA) reports of Alliance (11) and the IGNS revision (12) extracted a sub-catalogue of all historical earthquakes surrounding the site to a distance of 200 km. A number of different source zones were established based on geological structure and seismic history and these were sampled as part of the PSHA process. The PSHA results indicated that the East Sydney Basin area source, which encloses the Lucas Heights site dominates the seismic hazard, with the dominant earthquake mode being a magnitude M5.6 within 20 km from the site. This information was used in establishing the Design Response Spectrum for the RRR used in the PSAR and described more fully in the ANSTO Consolidated Seismic Report (6).

4. Results of the Near Field Study

ARPANSA received a copy for the near field studies in January 2001 (10) and the CEO of ARPANSA took it into account in his decision to issue a Construction Licence for the RRR (see section 3.29 of Ref 4). The study covered an area of 5km radius from the site and reported on faults and lineaments compiled from the literature and examination of rock exposures, road cuttings and natural exposures. The study revealed only a few small-scale normal faults with displacements less than 0.3m and none of the faults displaced soil or near surface material.

The ANSTO submission concluded that there was no evidence that the faults found were active or posed an earthquake hazard for the RRR site.

During the field work for the study, close attention was given to locating possible exposures of a dyke reported some 200m west and to the north of the site. No exposures of the dyke were found at that time although, as reported in the present ANSTO submission, later investigations found dykes on the reactor site, west of the reactor building planned footprint. However, it was envisaged in the ARPANSA RAR (4) that the excavations would need to be mapped and site trenching undertaken if the construction proceeded.

Conclusions of ARPANSA's IAEA Consultant

In his report to ARPANSA (13), the IAEA Consultant to ARPANSA reports on his review of documents (3, 10), his discussions with ANSTO and IGNS, and his visit to the site surroundings and site area. His findings and conclusions at that time with respect to the geology out to 5 km are summarised below:

- It is reasonable to infer that the site area geology and tectonics are similar to the geology and tectonics of the 5km radius area. However, a more comprehensive database of this area should be compiled containing all geological/tectonics elements inferred by literature data.

- Further consideration should be given to the style and amount of faulting at the site, site vicinity and near region of the site (including the Lapstone Structural Complex). This is because during the 14 of August meeting, the ANSTO Consultants pointed out the possible capability of the Lapstone Structural Complex.

The IAEA consultant considered it was important to assess the type of capability of the Lapstone Structural Complex feature in the context of the current tectonic regime of Australia given by the focal mechanisms and in situ stresses.

These matters have been addressed in ANSTO's submission to ARPANSA (1).

He also recommended that the PSAR Report be updated in order to include the new data and to eliminate some confusing or misleading statements given in its different Sections; eg. geo-technical chapter, seismological chapter (conclusive statements on the shallow earthquakes, such as the Picton earthquake, are expected). In this context the seismicity maps are very difficult to read therefore an additional one, including only the events equal and/or greater than Magnitude 4, could be beneficial in any revision of the PSAR. The inclusion of other data discussed during the meeting dealing with the absence of capable faults in the near regional and regional areas of the site should also be included in the revision to the PSAR.

5. Assessment and Mapping of the Site and Excavations

The second part of the site mapping study designed to document fractures (faults and joints) in rocks exposed in road batters and in the foundation excavation of the reactor and Neutron Guide Hall at the RRR site. The detailed geological mapping began in April 2002 and was completed in June 2002 and led to the identification, measurement and analysis of two main fault strands in bedrock exposures on the RRR site.

The exposures were recorded by photographing the exposed rock faces (see Figures 6.2, 6.7a, and 6.7b of the ANSTO Submission (1)). The exposures were also logged and grided by surveying and measuring their orientations (See Figures 6.3, 6.4, 6.5, 6.6, 6.8 and Fig 6.6 of the ANSTO Submission (1)). The main features of the faults are:

- They generally strike to the north-north-east (000^{o} - 020^{o}).
- Dip steeply (mostly 65^{o} - 80^{o} east and west).
- The eastern strand is an apparent normal fault and has dip separations of 1 to 1.3 metres in sandstone and mudstone beds.
- The western strand has an apparent displacement in the opposite direction to the normal fault and dip separation 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 fault traces are about 12m to 15 m apart in the excavations.
- 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 Attachment 8 of the reports submitted by ANSTO (1), a consulting geologist (Swan) states that the available kinematic indicators indicate the sense of movement on the faults is predominantly dip slip and the mapped structural relations preclude any significant strike slip. He considered the detailed maps of the faulting exposed in the north and south walls of the foundation excavation to be an accurate representation of the geological conditions in these exposures. He considered that the mapping of the fault zone at the site was conducted in accordance with accepted international standards of practice for fault assessment for nuclear related sites.

In Attachment 3 of the reports submitted by ANSTO (1) Professors A Gleadow and M Sandiford visited the site and made the following comments:

- A series of small faults has been exposed in the main excavation
- The characteristics of these faults are very clearly displayed in the north and south faces of the excavation
- Most of the faults exposed have a clearly normal sense of movement indicating formation in an extensional stress regime
- A series of dykes (about 0.5m width) occur to the west of the main excavation.
- The dykes are extremely weathered and consist virtually entirely of clay.
- The dykes occupy a set of fractures which have a similar orientation to the normal

faults in the main excavation, and are probably themselves small normal faults

Attachment 3 comments that the one of the faults (the western strand) has been mapped by IGNS as a reverse fault. Professor's Gleadlow and Sandiford were not convinced that the sense of movement of this particular strand is reversed. The presence of a reverse fault is important since it implies formation under a different (compressional) stress regime to that (tensional) responsible for the normal faults and may have occurred later.

Conclusions of ARPANSA's IAEA Consultant

In his report to ARPANSA (13), the IAEA consultant to ARPANSA reports on his review of documents Ref (3, 10), his discussions with ANSTO and IGNS, and his visit to the site surroundings and site area. His findings and conclusions at that time with respect to the site excavations are summarised below:

- In the reactor area excavation, it is clear that the fault divided into two branches. One is a normal fault with a maximum displacement in the Triassic sandstones of 1 meter. The other branch of the fault shows a possible reverse movement, which according to the ANSTO consultants, is indicative of the reactivation of this fault in the current tectonic regime of this part of Australia, that has existed for the past 20 million years.
- At a meeting with ANSTO's Consultants a preliminary set of paleomagnetic data for the reverse fault strand was presented. From this information it is likely that the last movement of this fault occurred at least 800000 years ago. However this age could be much older and further dating discussed methods at the meeting were expected to provide a more definitive assessment of the last movement of the fault.
- The site visit included visits to Trenches 1, 2 and also to Trench 4. In two trenches (particularly in Trench 4) it was observed that the extension of the fault running through the reactor excavation site does not disturb a probable alluvial/eluvial or weathered rock ("soil"), stratum.

ARPANSA's IAEA consultant indicated that the IAEA report 50-SG-S1 Rev 1 (9), provides suitable criteria for assessing fault capability in intra-plate areas. Although 800000 years represents a long interval, it would not be considered adequately conservative in comparison with the 20 million years that represent the age of the present (compressive) tectonic regime of this part of Australia. It was, therefore, necessary to obtain more precise dating of the last movement, which occurred along this fault.

Adequate geo-morphological considerations would be helpful in assessing the nature of the alluvium/eluvium/"soil" material, cited above, which was not affected by faulting. This could represent a significant reference datum for the definition of the last movement of the fault. In this regard, it is necessary to define the nature of this material and later to perform a model for its formation and potential complete erosion.

Both the IAEA and the Geoscience Australia consultants to ARPANSA agreed that, to the extent that gouge materials are present in the fault planes, these could also represent a significant reference datum for the definition of the last movement of the fault.

6. Interpretation of the Fault Data

ANSTO's Submission indicates that there are two different interpretations for the faulting:

- The first is that the eastern and western strands were formed during the opening of the Tasman Sea, 83 to 53 million years ago. This is based on the observation (Attachment 2 of (1)) that the fault dips at steeper angles than would be expected for a true reverse fault. Additionally, the exposure of this fault strand on the north face of the excavation is normal in character and down thrown to the west. In addition the dykes which predate any potential fault movements occupy a set of fractures that have a similar orientation to the normal faults and do not appear to have seen any significant disruption.
- The second interpretation is that the eastern and western strands were formed as a normal fault system during the opening of the Tasman Sea, with reverse re-activation occurring subsequently on one of the strands, and possibly both. This is the position of IGNS who did the mapping studies for the excavation and for the additional trenches.

The first interpretation would be indicative that the faulting occurred between 83 and 53 million years ago, while the second is more conservative in suggesting re-activation after 83-53 million years ago. The further analysis reported in the ANSTO submission to ARPANSA was performed to test this conservative assumption, and to date movements of the western strand using both direct and relative numerical dating methods.

In Attachment 3 of the report submitted by ANSTO (1) Professors A Gleadow and M Sandiford visited the site and made the following comments supporting the interpretation that there is no reverse faulting:

- There is a very significant change in orientation of the so called 'reverse" fault between the north and south faces of the excavation, which rotates across the vertical between south and north faces of the excavation. This casts doubts on the reverse geometry.
- The fault dips at steeper angle than would be expected for a true reverse fault, and
- The exposure of this fault strand on the north face of the excavation is normal in character and down thrown to the west.

In Attachment 8 of the reports submitted by ANSTO (1) a consulting geologist (Swan) supports the IGNS position that the fault zone was formed originally during an earlier extensional regime as a normal fault, and was subsequently re-activated by reverse faulting during a later compressional phase. Swan considers that the IGNS interpretation is consistent with the geological history of eastern Australia and the reported evidence of faulting from coal mines and tunnels. He is aware of the position taken in Attachment 3, but considers the IGNS interpretation is consistent with the reported evidence, and it is more conservative with respect to the implications for the timing of fault movements.

7. Investigation of the age of the Geological Faults

A number of approaches were used to constrain the age of the faulting in the foundation excavation for the RRR. These were:

- Find and date gouge material from within the fault itself.
- Analyse borehole material to date a pervasive deep weathering episode.
- Trace the fault to an area where there was overlying material that could be studied, both in terms of geomorphology and for dating purposes.
- An assessment of the age of nearby dykes.

In order to under take these approaches a number of trenches were dug to trace the fault across the site, and a trench was dug to the north of the site.

Both direct and relative methods of numerical dating were used to constrain the age of the fault and included:

- Study of the geomorphology and geochronology of the material in a trench where cover existed above the fault in Trench 4 and the Additional Geological Investigations (RRRP-7500-3BEAN-003-A - Attachment 1 (1b)).
- Optically stimulated Luminescence (OSL) to date the un-faulted strata that overlie the fault in Trench 4.
- Paleomagnetic dating using the magnetic signature of the rocks and relating that to the information known on magnetic reversals and on movements of the earth's magnetic pole. This was done for the main excavation and for a number of trenches including Trench 4.
- Fission track and (U-Th)/He dating of borehole material. The results are claimed to constrain the total depth and timing of deep erosion, which has occurred over the area and thus provide another measure for the minimum age estimate for the time of the fault.
- Potassium-Argon (K-Ar) dating of gouge material.

The main findings from these ageing studies are:

- The OSL data gives consistent ages of the overlying Quaternary material (in Trench 4) that range from 14,000 years in the upper aeolian layers to greater than 104,000 years in the sand layers above the fault itself. The material appears to have been transported to the site and may have been subject to various removal and replacement cycles. The paleomagnetic analysis of the clasts from Trench 4 and the geomorphology confirm that the material has been transported to the site, and is not simply weathered bedrock.

- The thermo-chronology indicates that the deep weathering episode, which post dated the fault, gives an interval of 35-10 million years since the last movement.
- Paleomagnetic results for ferruginous material laid down across the fault yields a mean age of 9 million years, and not younger than 5 million years

ARPANSA Consultant Comments

The Geoscience Australia advice to ARPANSA (18) indicates that they are generally satisfied with the ANSTO responses to their queries concerning the ANSTO Submission. The evidence presented appears to support the conclusion that the minimum age of significant fault displacement is constrained by the age of deposition of the ferruginous layer at 9 +/- 4 million years.

Paleomagnetic Results

With respect to the interpretation of the paleomagnetic results on which this based, Geoscience consider that the additional data provided by ANSTO provided a compelling case that no significant internal rotation of material has occurred within the oxidised material for at least 9 +/- 4 million years. This suggests that no significant movement has occurred since that time on the fault over which the oxide layer is draped.

Regolith interpretation

Geoscience Australia is satisfied that deposition of the sediments overlying the saprolite in Trench 4 postdated faulting. This would support a minimum age of faulting (using the OLS results) of >104, 0000 years. They also consider that the faults in Trench 4 are likely to be kinematically related to those exposed in the reactor hall excavation.

Fission Track Data

Geoscience Australia acknowledge the fission track data could be useful in establishing an overall chronology of the site in which the probable timing of the faulting can be broadly constrained. Its main utility is that it builds a body of evidence that the last fault movement occurred in antiquity.

Relevance of Dykes

The evidence that a minor reactivation of the fault strands might trigger sympathetic movement in the dykes structure, 56 metres away should be treated with caution. Geoscience Australia accept that the dykes might be part of a coherent set of faults, but do not accept that the undeformed nature of the dyke material supports the interpretation that no major reactivation of the whole set of faults has occurred since dyke emplacement. However, this in no way diminishes the conclusions that the age of reverse faulting deduced from the paleomagnetic samples.

Direct Dating

Geo-science Australia is satisfied that the K-Ar dating of gouge, host rock, and dyke samples favour an early Cretaceous age for movement on the faults that could be examined by the method. Nothing in the K-Ar evidence, nor indeed any of the other geochronological evidence, points to a young age for any of the fault movements. However, the key piece of evidence suggesting that movements on the faults is old remains the Group 2 paleomagnetic results.

8. Assessment of the Capability of the Fault

Surface displacement

The main reason for the assessment of the fault was to judge whether the fault is deemed "capable" ie. whether the fault has significant potential for relative displacement at or near the surface. The importance of this is that the RRR seismic design as described in the PSAR (3) and the Consolidated Seismic Report (6) is to provide margins against the vibrations and accelerations associated with an earthquake. The RRR, like all nuclear power plants (NPP) is however not designed to withstand permanent surface movement associated with surface breaking faults.

With respect to criteria for capability of a fault the report uses NPP criteria from the USA Nuclear Regulatory Commission (NRC) and the IAEA, and a comparison has been made with the more rigorous criteria from the IAEA Safety Guide (9). The Submission claims basis for assessing the capability is the geological and seismological investigations that have been carried out for the RRR site.

The IAEA Safety Guide (9) has two elements and these are individually addressed as follows:

> *Criterion 1 A fault shall be considered capable if it shows evidence of past movement of a recurring nature within such a period that it is reasonable to infer that further movement at or near the surface can occur. (In highly active areas, where both earthquake and geological data consistently reveal short earthquake recurrence intervals, periods of the order of tens of thousands of years may be appropriate for the assessment of capable faults. In less active areas, it is likely that much longer periods may be required).*

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's submission presented evidence that the most recent fault movement, based on paleo-magnetism, is at least 5 million years ago. The thermo-chronology indicates a minimum of 10 million years ago. In addition the fault shows no evidence of past movement or movements of a recurring nature within such a period. The submission argues that the evidence is sufficient to demonstrate that the fault is not capable within the confines of either the IAEA or NRC criteria.

> *Criterion 2 A fault shall be considered capable if it shows a structural relationship has been demonstrated to a known capable fault such that movement of the one may cause movement of the other at or near the surface.*

The NRC criterion is similar in wording and effect.

The nearest known possible "capable fault" to the site is the Lapstone Structural Complex (LSC) located approximately 35 km west of the site. The potential for the LSC being active was considered in the Alliance1999 report (11) and the IGNS 2001 report (12) of probabilistic seismic hazard assessments. Both of these reports were considered in the Regulatory Branch Assessment Report RB-ASR-09-02 of the Application to construct the replacement reactor. The geological investigations of the Lapstone complex and the coastal area, related to coal and gas exploration, indicate that similar zones to the LSC do not extend further east towards Lucas Heights. Also the submission claims that structural geology considerations place the LSC in a separate tectonic zone, west of the coastal zone in which the site occurs. Consistent with this geological finding the Alliance report showed that a bi-modal distribution of magnitude distance dominate the hazard at Lucas Heights as follows.

For all return periods and spectral periods, a modal magnitude and distance group is observed at about M5.5 to M6.5 and 10 km distance (within the coastal area). This implies that such a source could be a capable fault if the earthquake has a shallow focal depth. From precedent observations in historical earthquakes at those magnitudes no sympathetic or secondary movements are expected on the site fault.

A second group is observed at large magnitudes (from M7 to 8.1) and distances 30 to 50 km, associated with the LSC. Because of this substantial distance no secondary movement is expected to occur on the site fault.

The results of this dis-aggregation have been used to develop the design basis earthquakes and associated time histories for the site. This is reported in the Consolidated Seismic Report (6).

The ANSTO Submission also considered an additional criterion associated with capable faults included in the IAEA draft DS 302 on seismic Hazard Evaluation for Nuclear Power Plants (14), and shown below.

> *Criterion 3 A fault shall be considered capable if it shows the maximum potential earthquake associated with a seismogenic structure, as determined in section 4 (14) is sufficiently large and at such a distance that it is reasonable to infer that movement at or near the surface can occur.*

The ANSTO submission argues that the only seismogenic structure is the Lapstone Structural complex. The Alliance report (11) and the IGNS report (12) indicate the conservative repeat time for the LSC is 11-27 thousand years. The LSC thus would have ruptured many times in the past 5-13 million years, and the evidence is that this has not triggered any slip at the RRR site. Also as discussed under criterion 2 above the RRR site fault is not part of the LSC tectonic structure.

The ANSTO submission indicates that the fault data demonstrates that the fault is not considered capable when judged against either the IAEA or the US NRC criteria (15) for siting nuclear power plants

ARPANSA Consultants Comment

The ANSTO Submission (1) was sent to ARPANSA's Consultants on 12 September 2002. The report of the IAEA consultant to ARPANSA (13) indicates that his final conclusions and recommendations derive from the data discussed above in respect of his visit to the Lucas Heights construction site and surrounding area, his meetings with ANSTO and its consultants and from his subsequent review of the ANSTO submission to ARPANSA (1). He considers that the submission adequately addresses all the important matters raised in Australia and summarised above (see sections 4 and 5). In particular the data presented:

- Gives assurance that the fault found at the foundation of the RRR is extremely old, as a minimum and in the most conservative case, older than 5 million years. Therefore, according to the IAEA criteria, it is not considered to be a capable fault. This is also confirmed (in the Consultant's opinion) by the presence of the unfaulted saprolite layer in Trench N.4 (Attachment 9 of Ref 1).
- Gives assurance these faults are clearly not potential seismic sources and they do not pose a surface-fault rupture hazard.
- Supports the position that the Lapstone Structural Complex belongs to another seismo-tectonic province, therefore its potential capability does not affect the fault at the reactor site.
- Support the finding of the non-capability of the fault in the foundation rocks of the RRR site supports the conclusions derived in the PSAR with respect to seismic design for vibration.
- Show that the third criterion of the IAEA Safety Guide (14) is not necessary in this case, since the discovered faults are not capable. Furthermore the present database does not indicate the presence of significant seismogenic structures in the site or site vicinity areas.

With regard to the other items raised by this consultant to ARPANSA following his visit, he considers could be incorporated in the updating of the PSAR. Such an update would need to include any new data, and eliminate confusing or misleading statements in the PSAR.

In order to have a final and cohesive documentation of the data set for the RRR site and confirmation of the above conclusions, it is recommended:

- to update the PSAR, including the new data described above and also to eliminate confusing or misleading statements given in its different Sections; eg. geotechnical and seismological chapters;
- to complete the database of the site vicinity and site area, giving appropriate weight to what is requested in paragraphs: 311, 312, 313, 314, 315, 316, 329, 330, 331 of the IAEA, 50-SG-S1, Revision 1 (9). This database, requested since the first IAEA mission, is, in fact, still lacking of data, such as the geological/geomorphological mapping at scale 1:5000 of the site vicinity area.

9. Seismic vibratory design basis

The seismic design basis for the replacement reactor is derived from the PSAR (3) and probabilistic seismic hazard analyses (11) and (12), as discussed above. The seismic hazard analyses, rely 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.

The fault through the reactor building excavations is not now active, has not been active in the geologically recent past and is assessed to be extremely unlikely to re-activate within the foreseeable lifespan of the proposed facility. Characterisation of the fault has not found any features that distinguish it from the many hundreds of similar faults throughout the Sydney Basin. These faults were implicitly accounted for in the seismic activity attributed to the Sydney Basin zones in the probabilistic seismic hazard analysis.

Thus, the existing design response spectrum accepted in the Regulatory Assessment Report (4) as the basis for seismic design of structures, systems and components, approved in the Construction Licence, would not change due to the fault at the reactor site. The seismic design basis remains adequately conservative with regard to vibratory motion at the site.

10. Summary

The ANSTO submission to ARPANSA is based on the extensive geological investigations of the site for the replacement reactor at Lucas Heights. As indicated in the report and summarised above, the findings are based on inputs from many respected geological and seismic consultants (more than 20 people) acting as the lead scientific participants or as peer reviewers of the processes and findings. ARPANSA also relied on the advice of expert consultants (see Appendix 1 and Appendix 2 for their Curriculum Vitae) regarding the adequacy of the processes described in the ANSTO submission, and the findings with respect to the age of the fault and its capability.

The submission convincingly argues that the extensive study of the faults discovered in the reactor excavations have shown that the minimum age determined by paleomagnetism as 5-13 million years, which is consistent with the thermo-chronology results of 10-35 million years. The submission concludes:

- The faults on the site are not potential seismic sources and they do not pose a surface-fault rupture hazard.
- There is no need to alter the outcomes of the analyses already performed as part of the PSHA and used in the seismic design of the reactor, and
- There is no change required to the design hazard spectrum put forward in the PSAR in May 2001 (and modified in the Consolidated Seismic Report Jan 2002 to take into account the IGNS 2001 report).

The Geoscience Australia advice to ARPANSA indicates that they are generally satisfied those ANSTO responses (18) to the Geoscience queries (16) concerning the ANSTO Submission and in particular the methods used for ageing the fault (17). They agree that evidence presented appears to support the conclusion that the minimum age of significant fault displacement is constrained by the age of deposition of the ferruginous layer at 9 +/- 4 million years. The key piece of evidence suggesting that the movements on the faults are old, is the paleo-magnetic aging of the ferruginous material through the reverse fault.

The IAEA Consultant's report to ARPANSA indicates that the fault found at the foundation of the RRR is extremely old, as a minimum and in the most conservative case, older than 5 million years. Therefore, according to the IAEA criteria, it is not considered to be a capable fault. This is also confirmed, in the Consultant's opinion, by the presence of the un-faulted saprolite layer in Trench 4 (Attachment 9 of Ref 1).

ARPANSA's IAEA Consultant also states that the finding of the non-capability of the fault found at the foundation rocks of the RRR site supports the conclusions outlined in the in the PSAR with respect to seismic design for vibration.

The reviews that have been undertaken by experts from Geoscience Australia and the IAEA expert contracted by ARPANSA give confidence that the seismic design of the reactor structures, systems, and components important for safety should not be affected by the fault through the excavations for the foundations of the reactor building. The basis is the conclusions reached by these experts that the fault discovered is very old and not capable under either the US Criteria (15) or the IAEA Criteria (9).

11. Conclusions

The fault is not currently 'capable' within the IAEA or USNRC definitions of causing surface displacement. It is not now active, has not been active in the geologically recent past and is unlikely to re-activate within the foreseeable lifespan of the proposed facility. Consequently, this pre-existing fault presents no greater risk than the surrounding un-faulted material. Thus, the replacement reactor need not be designed for such displacement.

The existence of this 'incapable' fault does not impact on the probabilistic seismic hazard assessment from which the seismic design basis for the reactor was derived. Therefore, the existing design response spectrum accepted in the Regulatory Assessment Report (4) as the basis for seismic design of structures, systems and components, and approved in the Construction Licence, has not changed and remains adequately conservative with regard to vibratory motion at the site. The finding stated in the Regulatory Assessment Report remains valid. That is:

> *The reviews that have been undertaken by the Regulatory Branch and the IAEA experts contracted by ARPANSA give confidence that the seismic design of the reactor structures, systems, and components important for safety has been very conservative. The margins identified give a high confidence in a low probability of failure for all such structures, systems, and components at least twice those of the design basis earthquake.*

The proposed construction should be permitted on the existing excavated site.

References

(1a) ANSTO - Submission to ARPANSA on the Site Geological Investigations for the Replacement Research Reactor at Lucas Heights, RRRP-7500-3BEAN-002, 12 September 2002.

(1b) ANSTO - Additional Geological Investigations undertaken in support of the Replacement Reactor at Lucas Heights, RRRP-7500-3BEAN-003-A, 12 September 2002.

(1c) ANSTO - Replacement Research Reactor Project Tasks 1 and 2 - Site Fault Assessment Coffey/ IGNS Client Report 2002/103, September 2002.

(2) PPK - Replacement Nuclear Research Reactor - Draft Environmental Impact Statement, 1998.

(3) ANSTO - Preliminary Safety Analysis Report for the Replacement Research Reactor at Lucas Heights, May 2001.

(4) ARPANSA - Regulatory Branch assessment Report of the Facility Licence Application (FO118) to Construct a Controlled Facility, The Replacement Research Reactor, RB-ASR-09-02, April 2002.

(5) ARPANSA - Regulatory Assessment Principles for Controlled Facilities—RB-STD-42-00 Rev 1, October 2001.

(6) ANSTO Consolidated Report - Methods, Criteria, and Analysis for Seismic Qualification - Rev B, 21 January 2002.

(7) James W .Johnson - Review of the Seismic analysis and design of the Replacement Research Reactor Facility (RRRF), Lucas Heights, New South Wales, Australia - Final Report to ARPANSA, 5 February 2002.

(8) IAEA - Experts mission to Review the PSAR of the RRR for ARPANSA - Final Report, 10 July 2001.

(9) IAEA - Safety Guide No. 50-SG-S1—1979—Earthquakes and associated Topics in Relation to Nuclear Power Plant Siting.

(10) Task 1 –Replacement Research Reactor Project—Site Fault Assessment, Jan 2002 (See also Ref (1.c)).

(11) The Alliance - Seismic Hazard Analysis Lucas Heights Site of the High Flux Reactor, December 1999.

(12) IGNS - Extension to Lucas Heights Probabilistic Seismic Hazard Assessment, July 2001.

(13) Leonello Serva - IAEA - Review of the Assessment of Surface Faulting at the RRR Site Lucas Heights, Australia, October 2002.

(14) IAEA Draft Safety Guide Seismic Hazard Evaluation for Nuclear Power Plants— DS 302 Draft 1, November 2000.

(15) US Nuclear Regulatory Commission, Regulatory Guide 1.165, Fault Capability Criteria (see also US Regulatory Commission –10 CFR-Pt 100-App A- Seismic and Geological Siting Criteria for Nuclear Power Plants).

(16) Geoscience Australia – Questions and Clarification of ANSTO Submission to ARPANSA on Site Geological Investigations of Lucas Heights , 24 September 2002.

(17) ANSTO - Response to Consideration by Geosciences Australia of ANSTO Submission to ARPANSA on Site Geological Investigations of Lucas Heights, 4 October 2002.

(18) Geoscience Australia - Comments on ANSTO Response to Issues Raised by Geoscience Australia, 17 October 2002.

Appendix 1 - Curriculum Vitae for Dr Leonello Serva

BORN: October 22, 1951, at Cantalice (Rieti), Italy, Male.

EDUCATION: Doctor degree in Geology, University of Rome "La Sapienza", (1974).

POSITIONS HELD:

Since 1977 has been working with the Italian Committee for Nuclear Energy (CNEN-DISP), later ENEA-DISP and, from January 1994, ANPA: National Agency for the Protection of the Environment; at present Director of the Unit "Natural Risks" dealing with environmental aspects of natural phenomena, such as earthquakes, floods and landslides.

Since 1982 Consultant of International Atomic Energy Agency (IAEA) as Expert in geoseismological matters about sites for NPP's and LLW. As such he has taken part in more than 80 missions in 25 countries in 4 continents

1988-1994, Member of the National Committee for Earth Sciences of the National Council of Research (CNR).

1989-1994, Member of the National Committee (at inter-Ministerial level) for the Defence against geological-hydraulic risks .

1993-2000, Member of the Steering Committee of the National Group for the Defence against Earthquakes (CNR-GNDT).

Since 1996, Expert of the European Commission, Directorate General XII "Science, Research and Development", for the evaluation of european research projects dealing with Environmental Sciences (Natural and Technological Risks). **Since 1998** also Mid Term Reviewer of such research projects.

Since 2000, Contractor Professor at "Insubria" University of Como; course: geology and natural risks.

Scientific Contributions:

(1) Pioneering studies on the use of historical data for seismic hazard analysis, especially for NPPs and others critical facilities.

(2) Pioneering studies on the use of paleoseismological techniques in Italy and Europe.

(3) Pioneering studies on the use of paleoseismological data for seismic hazard analysis of NPPs and others critical facilities.

(4) Pioneering studies on the use of Holocene data for geologic-hydraulic hazard assessment.

Selected Publications:

A. Gurpinar, B. Mohammadioun, L. Serva and C. Stepp. (in press). Seismic hazard evaluation for nuclear power plants. Revision 2. Code of Practice, Safety Series 50-SG-S1, IAEA.

L. Ferreli, E.M. Guarneri, A. Hormes, A.M. Michetti,P. Perini, W. Rovinelli and L. Serva (in press). Evoluzione recente del paesaggio in Alta Valtellina: implicazioni sulla valutazione della pericolosità legata a deformazioni gravitative dei versanti e grandi frane. CNR-Fondazione CARIPLO, Special Issue: tettonica recente ed instabilità di versante nelle Alpi Centrali.

B. Mohammadioun and L. Serva (2001). Stress Drop, Slip Type, Earthquake Magnitude- and Seismic Hazard. BSSA, 91,4.

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F. Brunamonte, A.M. Michetti, L. Serva and R.E. Whítney (1995). Seismic hazard assessment from paleoseismological evidence in the Rieti Regìon (Central Italy). In: Perspectives in Paleoseismology, L. Serva and D.B. Slemmons Eds., AEG Special Publication N.6, 63-82, Seattle, WA, USA.

F. Brunamonte, A.M. Michetti L. and Serva (1995). Paleoseismological evidences in the epicentral area of the January 14-16, 1968 Belice earthquake (SW SICILY). In: Perspectives in Paleoseismology, L. Serva and D.B. Slemmons Eds., AEG Special Publication N. 6, 127-139, Seattle, WA, USA,

L. Serva (1994). The effects on the ground in the intensity scales. Terra Nova, 6, 414-416, Blackwell Scient. Pub., U.K.

C. Margottini, D. Molin and L. Serva (1992). Intensity versus Ground motion: a new approach using italian data. Engineering Geology, 33, 45-58.

Mallard, W. Hays and L. Serva (Working Group) (1991). Earthquake and associated topics in relation to NPP siting. - Revísion I. Code of Practice, Safety Series 50-SG-S1, IAEA, 70 pp.

E. Vittori, S. Sylos Labini and L. Serva (1991). Paleoseismicity: critical review of the state of the art. Tectonophysics, 193, 9-32.

Appendix 2 - Curriculum Vitae for Geoscience Australia Scientists

Dr Phil McFadden
Chief Scientist of Geoscience Australia
(formerly the Australian Geological Survey Organisation).

Dr McFadden is Chairman of the National Committee for Earth Sciences (a committee of the Academy of Science), a member of the National Stores Advisory Committee (a Federal Ministerial appointment), and a long-term member of the Commonwealth Committee for Co-ordination of Science and Technology (CCST). He also serves on several Academy and CCST working parties and committees.

He was Reader in Physics and Head of the Computing Centre at the University of Rhodesia (now Zimbabwe) when he was recruited to join the Research School of Earth Sciences, Australian National University in 1981.

He joined the Bureau of Mineral Resources (now Geoscience Australia) in 1983 as a Senior Research Scientist. In that organisation he has also served as a Principal Research Scientist, Branch Head (Computing), Senior Principal Research Scientist, Divisional Chief (Geophysical Observatories and Mapping), Chief Research Scientist and Chief Scientist.

His research interests have spanned paleomagnetism, geomagnetism, seismology, mathematical statistics, numerical analysis and computing systems.

He is the author of two books and many academic publications. In several instances he has represented Australia internationally in roles such as Chief Delegate to international bodies such as the International Union of Geodesy and Geophysics and the International Association of Geomagnetism and Aeronomy.

Academic Qualifications
B.Sc. (London) (1st Class Honours, Physics and Mathematics) 1970.
D.Phil. (Rhodesia) 1975.
Honours
Gold Medal of the Geological Society of South Africa, 1977.
Elected a Fellow of the American Geophysical Union, 1991.
Elected a Fellow of the Australian Academy of Science, 1996.

John F. Schneider
Group Leader, Geohazards Research
Geoscience Australia

Education
University of Wisconsin
Madison, Wisconsin
Ph.D. Geophysics (1984); M.S. Geophysics (1981)

University of California
San Diego, California
B.A. Mathematics with Specialization in Earth Science (1975)

Experience
Dr. Schneider is a seismologist with over 25 years experience in the development of earthquake and other natural hazard models and the assessment of risk natural hazard risk to urban centres.

2000-Present *Group Leader, Geoscience Australia, Canberra, Australia.* Responsibility for management and leadership of Geohazards research in the Minerals and Geohazards Division. Geohazards research comprises two main areas: the Urban Risk Research Group (25 staff), for research on earthquakes and other natural hazards and associated risk; and the Integrated Geophysical Network (22 staff), a national network of observatories for monitoring earthquakes, nuclear explosions and the earth's geomagnetic field.

1995 to 2000: *Chief Scientist and Senior Manager*, *Impact Forecasting/Aon, Chicago, Illinois, USA.* Directed research program in natural hazards risk assessment and led development of earthquake hazard models for implementation in catastrophe risk analysis software. Managed interdisciplinary projects addressing hazards and associated property and business interruption risk to hurricanes, earthquakes and operational risks for major corporations in the U.S. and internationally. Conducted key research on the development of new earthquake hazard models for California and the Central US, including the effects of ground shaking and collateral damages for soil failure, landslide and conflagration.

1994-1995: *Seismic Hazard Consultant, Menlo Park, California.* Led team of seismic hazard experts to develop scenario earthquakes and simulate ground motions for assessment of ground shaking hazard at Yucca Mountain, Nevada, site of proposed high-level nuclear waste repository. Principal clients: US Geological Survey, U.S. Department of Energy and Woodward-Clyde Federal Services.

1987-1994: *Electric Power Research Institute, Palo Alto, California.* Project Manager, Seismic and Geologic Hazards, Nuclear Power Division. Managed and developed numerous projects concerning issues in geology, seismology, geotechnical engineering, and seismic instrumentation.

Daniel James Clark
Structural Geologist
Geoscience Australia (Urban Geoscience Division, Neotectonics Project

Educational Background

1999 Doctor of Philosophy (Applied geology)
University of New South Wales
1994 Bachelor of Science (Hons 1st Class & University Medal)
University of Sydney
Geology, Geophysics, Mathematics, Civil Engineering Science

Professional Experience

Seismological experience in the construction and interpretation of earthquake focal mechanisms, the interpretation of earthquake waveform data and operation and deployment of earthquake aftershock recorders. Extensive field mapping and data analysis in remote areas within different types of terranes in Australia, New Zealand and Windmill Islands of East Antarctica islands. Collection of geological data and calculation of critical parameters relevant to the engineering design of the foundations for various structures, including pavements, buildings, towers, bridges and tunnels. Mapping, design and implementation of ground support for underground structures including tunnels and shafts.

Employment Experience

Feb 2001 to present
Structural Geologist
Geoscience Australia (Urban Geoscience Division, Neotectonics Project)
Sept 1999 to Dec 2000
Engineering Geologist
Connell Wagner Pty. Ltd. (Geotechnical and Tunnelling Section)
April to Sept 1999
Casual Research Assistant
School of Geology, University of New South Wales.
1995 to Sept 1999
Casual Lecturer, Tutor
School of Geology, University of New South Wales.
School of Geology & Geophysics, University of Sydney.
Nov 1993 to Feb 1994
Exploration Geologist
CRA Eastern Region

List of Publications

Clark D. & Leonard M. 2001. Principal stress orientations from multiple focal plane solutions: new insight in to the Australian intraplate stress field. Joint Geological Society of Australia and Geological Society of America Special Publication on the Australian Plate, in press.

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Clark, D. J., 1997. Rodinia Assembly: A perspective from the Fraser Mobile Belt, Western Australia. University of Sydney 6th Postgraduate Workshop "Geoscience Research in NSW", Sydney, N.S.W., p. 1 (abstract).
Clark, D. J., Hensen, B. J. & Kriegsman, L. M., 1996. Geology and evolution of a mid–Proterozoic continental margin, southern Fraser Orogen, Western Australia. Specialist Group in Geochemistry, Mineralogy and Petrology "Evolution of Metamorphic Belts", Latrobe University. Geological Society of Australia Abstracts, v42, p. 56–57.
Clark, D. J., & McCue, K., 2001. Lake George Fault Scarp Technical Tour Notes. Australian Earthquake Engineering Society Conference, Canberra: Earthquake Codes in the Real World. 7p, 7 Figs.

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