NATIONAL NUCLEAR REGULATOR

For the protection of persons, property and the environment against nuclear damage.

National Nuclear Regulator of South Africa Media Briefing on Measures Taken to Strengthen our Safety Regime and Nuclear Power Plants Operations Post Fukushima Daiichi Nuclear Accident

Date: 14 June 2012

Background

On March 11, 2011, a magnitude 9.0 earthquake struck off the northeast coast of Japan's main island followed by a devastating tsunami. The earthquake and tsunami left thousands of people dead or missing, about half a million homes destroyed or damaged and affected about 560 square kilometres of land.

The combined impact of the earthquake and tsunami on the Fukushima Daiichi nuclear power plant (NPP) caused a severe nuclear accident. In the hours and days that followed, the core of three of the six reactors at the Fukushima Daiichi site experienced significant core damage followed by a subsequent release of radioactive material to the surrounding region and to the sea.

The Japanese authorities initially rated the nuclear accident at level 4 on the INES scale (International Scale of Nuclear Incidents). They subsequently increased the level to 7, the highest on the scale. A final assessment of the severity and causes of the incident will come only after the conclusion of full investigations, expected to take several years.

While by any measure the accident at Fukushima Daiichi has been severe and negatively impacted the lives of a lot of people it is important to note that there were no reported deaths associated with exposure to radiation as a direct result of the Fukushima accident. Direct damage and casualties inflicted on Japan by the earthquake and tsunami far exceed any damage caused by the nuclear accident at the nuclear plant.

A number of workers reportedly received significant radiation doses (>100 mSv whole-body equivalent). These doses, although significant, would not be expected to cause any immediate physical harm, although there may be a small percentage increase in the workers' risk of eventually contracting a life threatening cancer.

Although full impact and root cause analyses are still to be completed, enough information is now available to begin the "lessons-learned" process. Following the Fukushima Daiichi nuclear accident regulatory authorities from 23 countries including South Africa, along with 4 regional and 3 international organisations, as well as the International Atomic Energy Agency (IAEA) amongst many other organisations contributed information on national response activities, stress test reports, and complimentary activities and assessments to the stress tests.

Summary of Findings and Lessons learnt from the event

Given the information that is available, the lessons learnt for existing and future nuclear installations are that:

- The Fukushima earthquake and subsequent tsunami was unprecedented as it impacted multiple units at various sites.
- The tsunami hazard may have been underestimated for the Fukushima Daiichi site. Accordingly, nuclear designers and operators should appropriately evaluate and provide protection against the risks of all natural hazards, and should periodically update these assessments and assessment methodologies in light of new information, experience and understanding.

- The event resulted in damage to emergency support infrastructure (offsite) that was destroyed by the earthquake and tsunami such as electricity supply, communication and transportation systems assumed to be available under emergency conditions.

- The accident demonstrated the value of hardened on-site Emergency Response Centres with adequate provisions for communication, essential plant parameters, control and resources. They should be provided for all major nuclear facilities with severe accident potential. Additionally, simple effective robust equipment should be available to restore essential safety functions in a timely way for severe accident conditions.

- Emergency arrangements, especially for the early phases, should be designed to be robust in responding to severe accidents.

- The tsunami damaged crucial piping of passive emergency cooling systems and disabled all electrical supplies including back up emergency diesel generators. Therefore defence in depth, physical separation, diversity and redundancy requirements should be applied for extreme external events, particularly those with common mode implications.

- Severe and extreme external hazards and long term combinations of external events should be considered in the design, mitigation and emergency planning arrangements. The earthquake and subsequent tsunami that affected Fukushima-Daiichi highlighted the need to evaluate concurrent related events, such as seismically induced fires and floods.

Extensive work on seismic events has demonstrated that significant margin exists beyond a well-formulated seismic design-basis.

- Some preliminary reviews suggest that, compared with the design against earthquakes, the design of Fukushima-Daiichi against tsunamis may not have been adequate and should have considered the recurrence of large-scale earthquakes in relation to a safety goal. It is clear from a simple review of historical data that an event significantly bigger than the design event could be reasonably foreseen with a relatively high frequency. This, perhaps could be regard as a major failing in the design basis of the Fukushima-Daiichi plants.

South African response and initiatives to the Fukushima accident

In response to the accident the NNR established a Task Team in April 2011 with the objective to:

1) Identify the lessons from the accident.

2) Conduct a comprehensive review of regulatory processes and regulations to determine whether the NNR should strengthen its regulatory oversight system to ensure continuous safety of operating nuclear installations in the country.

3) Conduct a comprehensive review of the safety of existing nuclear installations.

As we know the operator has the primary responsibility for safely operating the nuclear power plant and the regulator has the responsibility for independently assuring that nuclear plants are operated safely. In this regard, the NNR directed the operators of nuclear installations in South Africa namely Eskom and the South African Nuclear Energy Corporation (Necsa) to perform safety reassessments on the Koeberg and SAFARI-1 nuclear installations respectively considering the lessons learnt from Fukushima.

The aims of the safety reassessments were to:

(i) Identify vulnerabilities in the design basis of the facilities,
(ii) Evaluate the safety margins for beyond design events,
(iii) Identify necessary modifications, measures and technical features to be implemented where needed to strengthen defence-in-depth and improve safety of operating facilities.

Scope of the safety reassessment

The scope of reassessment covered, but was not limited to, the following:

a) **Provision taken in the design basis** concerning flooding, earthquake, other extreme natural phenomena and combinations of external events appropriate to each nuclear installation site.

b) **Robustness of the facility design** to maintain its safety functions beyond the design basis hazards
   (i) Earthquake exceeding the design basis
   (ii) Flooding exceeding the design basis
   (iii) Other extreme external conditions challenging the specific site
   (iv) Combination of events

c) **Consequential loss of safety functions**
   (i) Prolonged total loss of electrical power
   (ii) Prolonged loss of the ultimate heat sink

d) **Identification of potential cliff edge effects** in assessment of external events and safety functions in b) and c) and potential measures or design features to mitigate these effects.

e) **Accident management**

(i) Availability and reliability of accident management measures (Emergency diesel generators, hydrogen management, cooling, reliance on battery power, Emergency Operating Procedures and Severe Accident Management Guidelines, instrumentation, etc.) specifically considering events that potentially impact multiple facilities

(ii) On site response (facilities, resources and training)

(iii) Training of reactor operators for severe accident scenarios

f) **Emergency management and response**

(i) Emergency management actions and preparedness following worst case accident scenarios (Offsite response, arrangements and availability in emergency situations)

(ii) Radiological monitoring following nuclear accident involving radiological releases

(iii) Public protection emergency actions

(iv) Communication and information flow in emergency situations

g) **Safety considerations for operation of multi units** at the same facility site (facilities and resources)

h) **Safety of other fissile material and facilities**, e.g. safety of spent fuel storage in severe accident scenarios

In response to the directive from the NNR on May 2011, Eskom and Necsa submitted the respective safety reassessment reports in December 2011. The NNR completed its review of the reports submitted and notes the following high level conclusions:

1. The assessments conducted conform to the NNR directive and are in accordance with international practice.
2. The nuclear installations are adequately designed, maintained and operated to withstand all external events considered in the original design base.
3. There are no findings to warrant curtailing operations or to question the design margins of these facilities.
4. The safety reassessments identified a number of potential improvements to further reduce risk beyond the design requirements.

Overall conclusion

The NNR's regulatory standards and practices are in-line with internationally accepted standards and practices. With regards to the national nuclear regulatory framework, the NNR has consistently imposed deterministic and probabilistic principles as an obligation on the nuclear industry in South Africa. The NNR is regarded as a pioneer in this approach, which following the Fukushima accident, is attracting more attention worldwide.

The NNRs, regulatory approach has also had significant positive impact on the design and operation of the Koeberg nuclear power plant, resulting in modifications and accident procedures which are beyond what is typically required internationally.

The NNR has consistently enforced control of developments in the vicinity of Koeberg and is currently finalizing regulations relating to the control of developments around nuclear installations.

The NNR has nevertheless identified areas for strengthening the regulatory regime which will be addressed as part of the current review of the Regulatory Standards and Practices. These areas of improvements as identified by the NNR incorporates the lessons learnt from Fukushima and ensures that extreme external hazards and combinations of external events are incorporated in the design, mitigation measures and emergency planning arrangements. This will be the approach adopted by the NNR for considering any future potential nuclear licence applications. The areas for improvement relate to:

- Inclusion of specific requirements on common mode external events and combination of events for beyond design basis events
- Revision of the nuclear authorisation for SAFARI-1 to include provisions relating accident management measures
- Inclusion of specific provisions relating to testing and maintenance of all equipment included in the respective severe accident management measures.
- Inclusion of specific requirements related to the robustness of accident management measures and emergency planning arrangements considering beyond design basis external events.

It is also recommended that South Africa should perform a full self-assessment of all Emergency Planning and Response Infrastructures using the IAEA Emergency Preparedness Review (EPREV) and Self-Assessment guidelines.

Finally, in closing, I would like to emphasise that the safety reassessments have identified various improvements that need to be performed to further strengthen the nuclear safety standards in South Africa. Eskom and Necsa have been directed to implement these improvements in accordance with specific project timelines which are to be approved by the NNR.

The NNR is confident that the recommendations stemming from the stress tests will enhance principles of defence in depth when it comes to the safety of nuclear power generation in South Africa and further reduce the associated risks to as low as reasonably achievable.

Presentation 2

The nuclear accident at Fukushima

At the time of the earthquake on 11 March 2011 three reactors (Reactor Units 1 to 3) were operating, with Reactor Unit 4 on refuelling outage and Reactors Units 5 and 6 shut down for maintenance. When the earthquake struck all three operating reactors at the Fukushima-1 site shut down automatically and shutdown cooling commenced as designed.

As a result of the earthquake, offsite power was lost to the entire facility. The emergency diesel generators started at all six units providing alternating current (ac) electrical power to critical systems at each unit, and the facility response to the seismic event appears to have been normal.

Approximately 40 minutes following the earthquake and shutdown of the operating units, the first large tsunami wave inundated the site followed by multiple additional waves. The estimated height of the tsunami exceeded the site design protection from tsunamis by approximately 8 meters. The tsunami resulted in extensive damage to site facilities and a complete loss of AC electrical power at Units 1 through 5, a condition known as station blackout (SBO). The diesel generators at Unit 6 continued to operate normally.

Over the next few days several large explosions and fires occurred as a result of the fuel heating up, the fuel cladding reacting with water and steam and hydrogen being released. In addition, fuel element integrity was lost which led to a release of radioactivity into the environment.

The hydrogen explosions caused considerable damage to Reactor Units 1, 3 and 4. Reactor Unit 2 had an internal explosion that appeared to have breached the secondary containment.

Light water reactors require cooling of the fuel in order to remove heat generated by the core even after the reactor has been shut down. Cooling can be provided by various means and are design specific. Typically thought light water reactor designs require the supply of water either through passive and/ or active means. Engineered safety features include redundant and diverse systems to cool the reactor.

For over a week the personnel on site struggled to put cooling water into the reactors and the reactor fuel ponds. Electrical supplies were gradually reconnected to the reactor buildings and a degree of control returned. Heavily contaminated water used to cool the reactors and spent fuel ponds collected in uncontained areas of the site and leaked out to sea. Eventually emergency measures were successful in curtailing the uncontrolled discharges.

Safety of the SAFARI-1 Research Reactor at the Necsa site

SAFARI-1 (South African Fundamental Atomic Research Installation) is a 20 MW thermal tank-in-pool type, beryllium and light water reflected research reactor designed and built as a general research tool. SAFARI-1 falls in the class of research reactors commonly known as Materials Test Reactors (MTRs).

The SAFARI-1 reactor has been designed with multiple layers of protection including the provision of automatic actions such as reactor scram and shutdown, shutdown of the ventilation system and transfer to an emergency exhaust system, and the automatic backup of power supply in case of loss of offsite power supply.

The reactor has been designed with various passive engineered safety features such that natural convection cooling is sufficient to cool the reactor after a shutdown. There is no possibility of damage to the fuel if the reactor has been shutdown and no fuel degradation if the fuel is covered with water. Severe damage to fuel only becomes unavoidable if during a loss of coolant accident the reactor does not shutdown and the primary pumps are not available.

The SAFARI-1 reactor can survive an extended station blackout from full power without any damage to the reactor or spent fuel. The reactor will shutdown on external power loss even if the reactor protection system does not function as designed.

External flooding as a result of tsunami, precipitation, etc. has not been evaluated in the reassessment because it is considered highly unlikely due to the topography of the site.

Necsa performed a probabilistic seismic hazard analysis (PSHA) for the Pelindaba site which reviewed existing data relevant to the site seismic hazard. A Seismic Margin Assessment of the SAFARI-1 Reactor Building was performed which concluded that the SAFARI-1 building has a great deal of reserve capacity in terms of the ultimate shear strength offered by the walls at all levels of the structure. The assessment identified some vulnerability with the roof and floor slabs that will be addressed as part of the outcome of the safety reassessment.

The reassessment concluded that the SAFARI-1 plant has been adequately designed, and is maintained and operated to withstand all the external events that were considered in the original design base. Nothing has been found to warrant curtailing its operation or to question the integrated design margins inherent in the current facility.

Scope and major improvement findings from the SAFARI-1 Safety Reassessments

The SAFARI-1 safety reassessment considered extreme external natural events and included earthquakes, tornados, high winds as well as Loss of Offsite Power.

In general the safety reassessment performed by Necsa on the SAFARI-1 facilities addresses in broad aspects the requirements as set out by the NNR directive and are in line with the stress tests being performed internationally.

The improvement actions and/or recommendations which have been identified relate to plant modifications, severe accident management procedures and suitability and compatibility of emergency equipment. The NNR has directed Necsa to:

- expand the scope of the safety reassessment to include possible man made external events,
- complete the outstanding studies and analyses, and
- commit to a list of improvement actions to be implemented in the short, medium and long term.

Safety of the Koeberg Nuclear Power Plant

The Koeberg Nuclear Power Plant comprises 2 three-loop pressurised water reactor (PWR) units with their turbine generators and associated plant, each unit designed for a gross fission power output of 2775 MW thermal.

PWR designs typically have various passive engineered safety features in addition to multiple active engineered safety systems such as the steam driven auxiliary feedwater pump, steam driven main feedwater pump, the design for natural circulation of the primary cooling water, the steam generators with its own secondary water inventory that provides a heat sink for a limited time if not replenished as well as the big containment structure (about 4 times bigger than the typical BWR type containment) and associated free volume. The free volume allows for emergency depressurisation of the primary coolant system in to the containment without necessarily challenging the design pressures of the containment structure itself. At Koeberg passive hydrogen recombiners have been installed in the containment building to mitigate the consequences of hydrogen production which could result in case of challenges to the cooling of the fuel rods.

The studies performed in relation to the Koeberg site indicate that the likelihood of an earthquake or tsunami hazard occurring in the region is relatively low.

Consistent with the concept and principle of defense-in-depth, adequate provisions are in place to mitigate consequences of similar type of events. The Koeberg Nuclear Power Plant is robustly designed to withstand potential earthquakes and external flooding events such as tsunamis. Both the actual structures that form the containment and the engineered safety systems have been designed and built to meet required standards and to withstand an earthquake resulting in a peak ground acceleration (pga) of 0.3g at the site and is constructed on a seismic raft as part of the design provisions to withstand the design basis earthquake. The design also considers a tsunami of 4m and the plant is conservatively located at about 8m above mean sea level. In addition, the Koeberg Nuclear Power Plant has well-established and practiced General Operating Rules including emergency operating procedures in place that include severe accident management guidelines designed to bring the plant to a safe shutdown condition in the event of severe accidents. Based on risk studies additional safety measures have been implemented at Koeberg over the years, such as procedures for loss of ultimate heat sink, passive hydrogen recombiners, additional electrical power supplies, etc. Koeberg was among the first plants in the world to implement severe accident management guidelines, and to include these in the training of reactor operators. The definition of the seismic hazard is currently being revisited as part of the new build siting process using internationally implemented state of the art methodologies.

The reassessment revealed that the Koeberg plant has been adequately designed, and maintained to withstand likely external events that were considered in the original plant design.

Scope and major improvement findings from the Koeberg Safety Reassessments

The Koeberg safety reassessment included the following external events:

1) Seismic
2) Tsunami
3) Flooding
4) Fire
5) Aircraft crash
6) Explosion hazards
7) High winds
8) Tornados
9) Oil spill
10) Jellyfish ingress
11) Loss of Offsite Power
12) Station Blackout

The safety reassessment further evaluated the accident management arrangements, emergency plan provisions and means to minimise offsite releases.

The review concluded that the safety reassessment meets the NNR directive, and is consistent with international practice and addresses in broad aspects the objectives as set out by the directive. Eskom further followed the Institute of Nuclear Power Operations (INPO) and the World Association of Nuclear Operators (WANO) directives which addressed the immediate needs arising from the response to the Fukushima accident.

The external event safety reassessments performed resulted in the identification of proposed hardware modifications and improvement actions. These plant design modification proposals require detailed assessment to determine a feasible and integrated plant design modification solution.

However, in order to maintain or restore core cooling, and containment and spent fuel pool cooling capabilities under extreme external events, a plant design modification strategy based on the use of portable, on-site equipment and consumables is being implemented. The plant modifications required for the use of portable emergency equipment are currently in progress in the project definition phase. This scope of work includes installation of dedicated connection points for the proposed portable equipment, as well as associated instrumentation systems and electrical connections.

Additional identified short-term design modifications being considered include the following:

- upgrading both on-site and off-site communication systems;
- strengthening key equipment to further improve seismic robustness;
- installing hardened instrumentation systems for critical equipment and locations;
- improving emergency lighting on the plant, and
- constructing a robust portable equipment storage facility.

The safety reassessments performed further identified hardware modifications that could potentially enhance the robustness of the facility to cope with extreme external events that have been prioritised as long-term improvement actions. The implementation of these interventions would increase plant safety margins, provide greater flexibility and diversity for accident management and in some cases remove or extend the identified cliff edges.

Eskom is proceeding with the project definition phase to address the findings from the completed studies. In accordance with project management principles, the definition phase will drive the feasibility assessment which will inform the investment decisions. All modifications that can be shown to be feasible will be implemented in line with normal safety reassessment implementation windows.

In conclusion, while the plant has been shown to be adequately designed and operated, the reassessment has identified numerous improvements that are feasible to reduce even further the risk of external events. The improvement measures have been prioritised and short-term actions are being implemented. It should also be appreciated that the implementation of the longer term improvement actions requires careful consideration, planning and time for implementation in line with good engineering practices, sound system engineering, ALARA and project management principles. Eskom is in the process of completing the outstanding studies and analyses and has been directed to commit to a list of improvement actions to be implemented.

Note for the Editor

The National Nuclear Regulator (NNR)

The National Nuclear Regulator (NNR) is a public entity which is established and governed in terms of Section 3 of the National Nuclear Regulator Act, (Act No 47 of 1999) to provide for the protection of persons, property and the environment against nuclear damage through the establishment of safety standards and regulatory practices.

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