# Lessons learnt from the Fukushima incident

by Prof Johan Slabber

**The recent events at the Fukushima Nuclear Plant in Japan, which followed the massive earthquake and tsunami, have been the source of major concern regarding the risks associated with nuclear power plants. A number of the reports in the media have conveyed rather conflicting opinions that have served to confuse rather than clarify the situation.**

Nuclear fission power is produced when the nucleus of an element – usually uranium – splits into parts and in the process releases a relatively large amount of energy. In a nuclear reactor, this phenomenon takes place in the part called the reactor core.

The splitting process in reality forms new combinations of particles that make up the nuclei of the resulting products, and elements are created that are radically different from the original uranium. These elements are called fission products and are normally very radioactive.

*In the design requirements of power reactors, external events that may have an impact on the safety of the reactor are always stipulated for a specific site.*

Radioactivity can be seen as the release of excess energy from a very excited nucleus. As the energy is released, the degree of excitation decreases. This phenomenon is generally known as radioactive decay. The release of energy in a fission reaction comes at a price. This price is the creation of very radioactive fission products. It is a design objective for any reactor to provide successive barriers around the fuel material to inhibit the release of these highly radioactive fission products into the environment. The energy released by the radioactive decay of the fission products is deposited by reabsorption in the core and surrounding structures.

When the reactor is operating, this heating is less than 10% of the reactor power. However, when the reactor shuts down and the fission energy is reduced to practically zero, the heating from the absorption of fission product radiation energy becomes the main source of heating in the core, as well as in used fuel elements that might have been discharged from the reactor core.

During accident conditions (where cooling of the fuel is abnormal), there are two sources of heating in the reactor core and used fuel elements that need to be considered. The first is the fission product radiation heating, while the second is the heating due to an exothermic chemical reaction between the zirconium in the fuel-cladding material and its surrounding environment. In addition to the heat generated by this reaction, in the order of 500 $m^3$ of hydrogen per ton of zirconium oxidised is produced. It is therefore clear that if the fuel heats up to beyond a certain value, the integrity of the fission product barrier

**Prof Johan Slabber**, former Chief Technology Officer at the Pebble Bed Modular Reactor (PBMR) Company (Pty) Ltd and currently associated with the University of Pretoria's Department of Mechanical and Aeronautical Engineering, recently presented a lecture on campus to explain what happened at Fukushima, starting from the generic basic principles on which reactor technology is based. He also illustrated that what happened at Fukushima was rather predictable, given the current boundary conditions surrounding the plant. He explained some of the features of the Koeberg nuclear power plant and highlighted the capability of this plant to handle external events of this nature.

→ *The Fukushima nuclear power plant.*

is challenged by two synergetic heating processes, accompanied by the production of an amount of hydrogen, depending on the mass of zirconium consumed in the process.

It is therefore clear that sufficient cooling must be available to keep the fuel elements cold enough to safeguard against degradation of the primary fission product release barrier (in other words, the zirconium cladding) during all modes of operation, as well as when the reactor is in a shutdown state.

## The Fukushima incident

In the design requirements of power reactors, external events that may have an impact on the safety of the reactor are always stipulated for a specific site.

It is accepted practice to design for an earthquake of a certain magnitude and the possibility of flooding. For sites along the coast, this requirement normally includes tsunamis of certain intensity and flooding elevations.

From the sketchy information released by the Japanese authorities, it appears as if the tsunami flooded and damaged the cooling water intake equipment and structures of all four reactor units. This could have resulted in a total loss of main heat sink for the heat generated in the cores of three units and the unloaded fuel from the fourth unit, as well as older fuel stored in the fuel storage pond of all four units.

The heat generated by only the fission products one week after shutdown by one unit is roughly estimated at 6.5 MW. The plant seem to have survived the earthquake and the diesel engines that need to supply power in the event of a loss of off-site power to the cooling systems started. Forty minutes later, the tsunami knocked out all off-site power connections, as well as the diesels. Batteries took over, but died after some hours. With no power, water couldn't get anywhere.

It is clear from the reports that the power supply was eventually restored to some extent, but since a sufficient source of reactor-grade cooling water was unavailable, sea water was used directly on the heated fuel elements and structures. The time taken to get this operation going seems to have caused the fuel elements to overheat and an explosive quantity of hydrogen was produced due to the chemical reaction. From the television footage that was shown, it is clear that explosions occurred at the facilities, which blew off some of the cladding material that was used at the top of these reactors. This does not necessarily imply that the reinforced concrete buildings that acted as the last physical barrier against release were damaged.

The question now is what can be expected in the days to come? An answer to this question is based mainly on speculation, but some clear indicators already exist. The hydrogen explosions suggest that the cladding tubes that were supposed to contain the fission products were degraded. Degradation would most probably have resulted in an increase in the release of radioactivity into the building environment. If the ventilation system had been operational, then one could have

→ *The Koeberg nuclear power plant.*

expected some degree of filtration and dilution of the concentration of the radioactivity. However, some of these radioactive fission products were of a gaseous nature and some were even noble gases. If the plant manages to maintain cooling for the next months or even years and restore the containment with efficient ventilation around the damaged fuel elements, the radioactive releases will diminish. If not …?

## The Koeberg design

All the nuclear reactor facilities in Japan are built close to the notorious "ring of fire". In the case of Koeberg, the situation is very different. Although the Cape is seismically very stable, Koeberg was designed with substantial conservatism using the Ceres-type seismic event on the Milnerton fault as basis. This fault is nine kilometres offshore. In addition, the nuclear island, which consists of the Nuclear Steam Supply System (NSSS) and fuel building, is supported by a large number of aseismic bearings that are specifically designed to reduce the peaks of horizontal building acceleration during a specified earthquake.

Although no tsunamis have ever been recorded on the West Coast, the design of Koeberg includes allowance for a three-metre tsunami under the assumption that the tsunami will coincide with maximum spring tide, a major storm surge and maximum wave height. This resulted in a total height of seven metres above mean sea level. The Koeberg terrace height is eight metres above mean sea level. As a modification to the plant subsequent to the Three Mile Island accident, platinum-based hydrogen recombiners were installed in the containment buildings of the two reactors to eliminate possible hydrogen explosions.

## What is radiation?

Radiation is energy carried away from an excited nucleus of radioactive elements. This energy can be carried by energetic, charged particles or by electromagnetic radiation. Where this radiation interacts with a medium, energy is deposited. If the medium is a human being, then – depending on the nature and quantity of the energy bearing radiation – the energy deposited can damage or kill cells.

The importance of safety in the nuclear industry is generally recognised and – except for the use of radiation in medicine – strict standards for radiation exposure have been developed. This is fortunate, because so many of the devices of modern technology, such as accelerators, nuclear reactors, television sets and high-flying aircraft, represent potential sources of radiation exposure.

Notwithstanding the accidents that have occurred in nuclear facilities so far, the nuclear industry has contributed very little by way of radiation injury either to its own personnel or to the general public.