(The Ghana Nuclear Power Programme Organization (GNPPO) is mandated with the task of coordinating, overseeing and administering the phase-to-phase implementation of the Nuclear Power Programme in Ghana until the commissioning of Ghana's first nuclear power plant.)

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GNPPO NEWSLETTER

FUKUSHIMA NUCLEAR ACCIDENT

BACKGROUND

There are 447 commercial nuclear power plants in the world, operating in 30 countries as at 1st August 2017, with total installed capacity of 392,000 MWe (Megawatt electric). Twenty (20) new nuclear power plants were connected to the grid in the last two years, the highest number since the 1980s, while 58 nuclear power plants with a total capacity 62049 MWe are under construction in 14 countries. One hundred and sixty two (162) nuclear power plants have been planned with additional 349 nuclear power plants proposed.

Japan relies on nuclear power for a third of its electricity production and has 54 nuclear reactors operating in the country. In the city of Fukushima (towns of Okuma and Futaba in the county of Futaba), is the Fukushima Daiichi Nuclear Power Station, which houses 6 units of boiling water reactor types. Unit 1 has an installed capacity of 460 MWe; each of units 2, 3, 4 and 5 have 784 MWe and unit 6 has 1100 MWe of installed capacity (total installed capacity is therefore around 4700 MWe). At the time of the Fukushima accident, only three reactors were in operation (unit 1, 2, and 3); the remaining three units (4, 5, 6) were already in shut down mode undergoing periodic/planned maintenance.

LIGHT WATER REACTORS (LWRs)

Of the over 400 Nuclear Power Plant used to generate electricity in the world, more than 90% are light water reactors (LWRs). Generally there are two types of LWRs: the boiling water reactors (BWRs) and the pressurized water reactor (PWRs). The basic principle in BWRs and PWRs is the same, i.e. they generate heat by fission (splitting atoms), the heat turns water into steam, which directly drives the power-generating turbines, and the electrical generator connected to them to produce electricity. It must be emphasized that other sources like coal, oil or gas have the same principle, the difference being the source of fuel or how the heat is generated.

The main difference between BWRs and PWRs lies in how the steam is generated. In BWRs, the heat in the core of the reactor directly turns the water into steam, whereas in PWRs, the heat generated by fission is transferred to a secondary loop via a heat exchanger (steam generator), where the steam is produced or generated. In both BWRs and PWRs, after flowing through the turbines, the steam turns into water in the condenser. The water required to cool the condenser is taken from and returned to a nearby ocean, river, or water supply. All the Fukushima Daiichi units were of the BWR type.

UNDERSTANDING THE HEAT SITUATION

Uranium is the basic fuel used in nuclear power plants. The fuel is usually uranium oxide (UO_2) in the form of pellets that are arranged in tubes to form fuel rods. Lots of the rods are bundled together, arranged in a certain pattern called a fuel assemble in the reactor core. The uranium atoms, once the reactor is started, is expected to split continuously while releasing large amounts of heat. Because the splitting is initiated and continued by neutrons, prevention of "too much heat" can be done through controlling the number of neutrons, as well as using a very active cooling system. To control the neutron number at any time, neutron-absorbing materials (boron, cadmium etc.) in the form rods are used.

It must be noted that splitting atoms produce daughters (by-products) that give off heat too, so even when a nuclear power plant is shut down, the reactor still gives off heat and requires continuous cooling. The coolant (heavy water or light (normal) water) used to manage this depends on the type of reactor, and for that matter, the reactor design. With specific reference to the Fukushima Daiichi BWRs light water is the coolant.

THE FUKUSHIMA ACCIDENT

Earthquake

Japan has a notorious earthquake history and on Friday, March 11, 2011, at 2:46 p.m. (Japan time), the country recorded one of the largest earthquakes ever in its history, and that of the world. The earthquake's magnitude was recorded as 9.0 on the Richter scale. The Richter scale, invented in 1935 by Charles F. Richter, is used to rate the magnitude of earthquake and a scale of 9 is associated with near total destruction.

The Earthquake tremors triggered the automatic shutdown of three reactors, units 1, 2, and 3 that were in operation at the time; the other three of the six reactors (units 4, 5, and 6) at the Fukushima power plant were already off for maintenance, and were undergoing continuous heat decay cooling.

The earthquake caused loss of power to the nuclear power reactor site. This was due to the collapse of an embankment that in turn brought down the steel electrical towers. Because there was damage to the electrical circuit breakers and disconnection of switches, power to the site was disrupted. Backup diesel generators for such emergencies were immediately activated to provide power within the plant. Cooling systems were also launched automatically, thus ensuring that the emergency response systems of the operating nuclear power plants worked as expected.

A resident stands on rubble in Ozuchi, Iwate prefecture, on 15 March

Tsunami

A tsunami is an enormous sea wave that erupts and reaches land. The earthquake triggered a tsunami within a short period of its occurrence. Exactly forty-one minutes after the earthquake, the first of several tsunamis arrived at the site. The maximum tsunami height impacting the site was estimated to be 46 to 49 feet (14 to 15 meters), which exceeded the design basis tsunami height (the estimated height for possible tsunami considered for designing the plant) of 18.7 feet (6.1 meters), and was above the site grade levels (the actual height of the site) of 32.8 feet (10 meters). All the above show a tsunami of that magnitude and height (i.e., 14 -1 5 metres) was not considered in the design of the power plant.

The tsunami therefore, inundated and completely flooded the diesel engines that had earlier responded to the loss of power to the plant. AC power supply equipment was also affected negatively. Obviously the cooling system depended on power supply and was relying on power supplied by the emergency diesel engines, so the tsunami effectively knocked out this power source. The tsunami also overwhelmed and damaged the seawater pump, leading to loss of the residual heat removal system. This meant heat within the reactor could not be removed, as was required.

The earthquake and the accompanying tsunami had major effects on the country. Over 500,000 people were displaced, and over 18,000 lives were lost. In addition, millions of buildings were destroyed or damaged.

Total Loss of Power and Core Meltdown

There was a total loss of DC power sources to Units 1, 2, and 4, and the central control room instrumentation. It became impossible for plant operators to monitor plant condition and operate to restore normalcy. Eventually, unit 3, which earlier had its DC power system functioning, also encountered challenges because of battery run out. Consequently units 1–4 were faced with total loss of power.

The core contains the fuel assemblies, the moderator and control rods. The nuclear reactor core is where the chain reaction (splitting of atoms) takes place to release the energy in the form of heat. With the loss of power and cooling system, there was a huge challenge at the Fukushima Daiichi plants. The situation resulted in a core meltdown (core damage from overheating).

It must be emphasized that the natural disaster affected several other nuclear power plants but they underwent automatic shutdown, and they did not lose their backup cooling system. In particular, four reactors at the Fukushima Daini site also experienced the earthquake and tsunami, but the reactors automatically shut down and had no subsequent problems due to their "superior" location.

Corbis-RM-fukushima-disaster-damaged-building

Hydrogen Explosions

To offer protection to the fuel, the outer layer of the fuel rod called cladding is made from a mixture of metals with the major metal being Zirconium, and the metal mix called Zircaloy. Zircaloy is used due to its unique properties — low neutron absorption, heat transfer properties, corrosive resistance even at temperature of 300°C, and other mechanical properties. With loss of cooling and the resultant high temperatures, the zirconium reacted with water to produce hydrogen.

The buildup of hydrogen generated during the accident, collected within the reactor buildings and caused explosions in the upper portions of the unit 1, 3 and 4 reactor buildings. The spent fuel pools in these buildings were exposed leading to releases of radioactive materials into the environment. It must however be stated that there was no damage to the spent fuel itself.

Environmental Impact

There were emissions of radioactive materials into the environment due to the explosion. There was a need for the deliberate venting of the pressurized reactors, and large amounts of water being pumped or sprayed into the reactors to aid with cooling process. As such, contaminated water got discharged (with some leaks occurring) into the ocean. It is reported that by 10:00 pm of March 11 2011, rising radiation levels were observed in the reactor and turbine buildings, giving a clear indication of core damage. Subsequent survey conducted revealed contamination of soil, milk, beef etc. There were, however, no deaths as a consequence of the nuclear radiation exposure, and for that matter the nuclear accident. There however remains some residual scientific debate on more general terms about the possible future health impacts.

Emergency Response

A nuclear emergency was declared by the government of Japan on 11 March 2011. The Japanese government initially set up an evacuation process:

- a prohibited access area up to 3 km from the plant,
- an on alert area of 3 to 20 km from the plant,
- evacuation prepared area of 20 to 30 km from the plant.

These evacuation areas were based on radioactivity levels above 20 mSv. On first day of the disaster, about 134,000 people who lived between 3 and 20 km from the plant were evacuated. Additional 354,000, living between 20 and 30 km from the plant, were evacuated four days later. The Japanese Prime Minister issued instructions for people within a 20 km zone of the Fukushima Daiichi nuclear plant to leave; he urged those living between 20 km and 30 km from the site to stay indoors. The Japanese government later released a roadmap for the cleanup activities. The Tokyo Electric Power Company (TEPCO) also began using remote controlled heavy equipment to remove debris from around nuclear reactors 1–4.

The debris was as a result of the tsunami which washed away vehicles, heavy machinery, oil tankers, gravel, buildings, other machinery, etc. TEPCO announced intentions to restore the automated cooling systems to the damaged reactors and have them put into cold shutdown status in six months. To assuage the fears of all citizens, the government enacted an order to decontaminate areas with recommended levels of radiation for which decontamination was needed.

LESSONS LEARNT FROM THE ACCIDENT AND RECOMMENDATIONS

The International Atomic Energy Agency (IAEA) produced a detailed report (The Fukushima Daiichi accident — International Atomic Energy Agency, Vienna, 2015) on the Fukushima Daiichi accident.

According to the report, there were no indications that the main safety features of the plant were affected by the vibratory ground motions generated by the earthquake on March 11, 2011. This was due to the conservative approach to earthquake design and construction of NPPs in Japan, resulting in a plant that was provided with sufficient safety margins. However, the original design considerations did not provide comparable safety margins for extreme external flooding events, such as tsunamis.

The design of the Fukushima Daiichi NPP provided equipment and systems for the first three levels of defence in depth:

- equipment intended to provide reliable normal operation;
- equipment intended to return the plant to a safe state after an abnormal event; and
- safety systems intended to manage accident conditions.

The design bases were derived using a range of postulated hazards; however, external hazards such as tsunamis were not fully addressed. Consequently, the flooding resulting from the tsunami simultaneously challenged the first three protective levels of defence in depth, resulting in common cause failures of equipment and systems at each of the three levels.

The regulatory inspection programme in Japan was rigidly structured, which reduced the regulatory body's ability to verify safety at the proper times and to identify potential new safety issues.

The report noted that the consideration of mainly historical data in the establishment of the design basis of NPPs is not sufficient to characterize the risks of extreme natural hazards. Even when comprehensive data are available, due to the relatively short observation periods, large uncertainties remain in the prediction of natural hazards. The report further stressed that the assessment of natural hazards needs to consider the potential for their occurrence in combination, either simultaneously or sequentially, and their combined effects on a nuclear power plant as well as their effect on multiple units at a nuclear power plant.

In the area of regulatory oversight, the report concluded that for effective regulatory oversight of the safety of nuclear installations, it is essential that the regulatory body is truly independent and possesses legal authority, technical competence and a strong safety culture. In preparing for the response to a possible nuclear emergency, it is necessary to consider emergencies that could involve severe damage to nuclear fuel in the reactor core or to spent fuel on the site, including those involving several units at a multi-unit plant possibly occurring at the same time as a natural disaster.

From the lessons learnt from the Fukushima accident, the following are some of the actions being taken by the GNPPO:

1. The GNPPO is ensuring that all reactor designs under consideration have fully taken all Fukushima related lessons into account.
2. That it ensures that a critical assessment of all external hazard events is taken into account for the selected site for the nuclear power plant
3. True independence of the regulatory body is established. In this regard, discussions are ongoing on placing the Nuclear Regulatory Authority under a separate Ministry from the promoters, i.e. Ministry of Energy and Ministry of Environment, Science, Technology & Innovation.
4. Focusing seriously on the development of a robust integrated management system for all organizations within the nuclear programme.

CURRENT STATE OF FUKUSHIMA DAIICHI NUCLEAR POWER PLANT

Fukushima Daiichi Units 1–3 were heavily damaged in the March 2011 disaster. Unit 4 suffered less severe damage, but its reactor building was destroyed by a hydrogen explosion caused by a shared ventilation line with Unit 3. Units 5 and 6 remain undamaged but the overall contamination of the area will make operation impracticable now. Despite immense technical challenges, clean up continues. Since March 2011, all six reactors at the Fukushima Daiichi site have been shut down.

No. NPID-127541-NWL-008 | Editor: Elikem K. Ahialey | Mobile: 233507011480 | Email: info@npi.gaecgh.org