(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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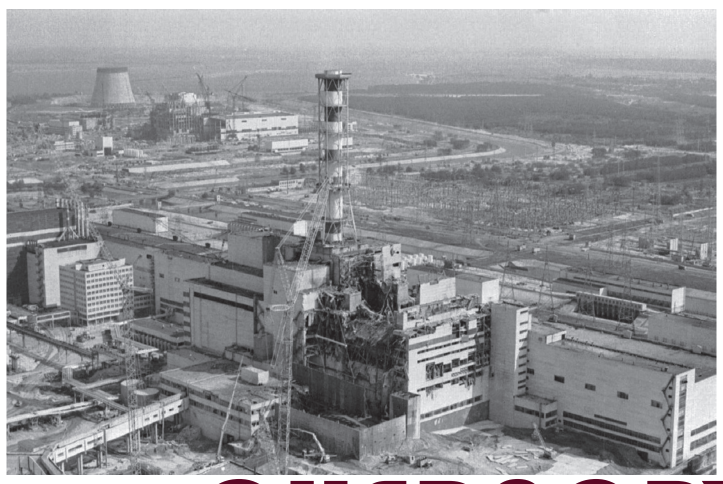

CHERNOBYL NUCLEAR DISASTER

BACKGROUND

Nuclear research, specifically into nuclear weapons, by both the USA and the Soviet Union was pushed farther by the Cold War as each block wanted to come out with the most powerful weapons.

Aside from the Cold War, the USSR turned to nuclear power for electricity because of problems with oil and gas at the time. Additionally, the coal industry was experiencing high death rates and they needed cheaper and guaranteed supply of electricity for heavily industrialised and populated regions of the union. The USSR, therefore, pursued their nuclear agenda and by the time of the accident at Chernobyl, they had become reliant on nuclear power as a relatively cheap and sustainable form of energy.

The Chernobyl Power Complex consisted of four nuclear reactors of the RBMK-1000 design. The city of Chernobyl, after which the nuclear power plant was named, is located about 15 Km from the plant with a population of 12,500 at the time of the disaster. About 3 km away from the reactor is the new city Pripyat. Pripyat was created because of the nuclear power plant and with 49,000 inhabitants at the time of the accident.

RBMK-1000 (the type of Reactor Design)

The RBMK, a Soviet-designed reactor with full name reaktor bolshoy moshchnosty kanalny in Russian (high-power channel reactor in English), is a water-cooled reactor with graphite as its moderator. It is also known as the light water graphite reactor (LWGR). It must be noted that the RBMK is very different from most other power reactor designs as it was derived from a design used principally for plutonium production and was intended and used in Russia for both plutonium and power production. The combination of graphite moderator and water coolant is found in no other power reactors in the world today.

MODERATORS

The moderator and control rods together control the rate of reaction in the core of the nuclear reactor. Neutrons released from the chain reaction must move at the 'right' speed for the atoms of uranium to capture them. The moderator is, therefore, a material which slows down the speed of the neutrons in order for "effective" fission to occur. Several materials can be used as moderator but the choice of moderation material must take into account the size of material to be moderated. From the laws of physics, a particle can better be slowed down when it collides with size-comparable particle than when it collides with a far bigger particle. Considering the fact that the particle to be moderated is neutron (mass number=1), water would be a very good moderating material in nuclear power plants. Imagine a table tennis ball colliding with a bowling ball, as opposed to the same table tennis ball colliding with an orange-size table tennis ball.

Commonly used moderators are water (regular/light water) and heavy water. Solid graphite, Beryllium and beryllium oxide (BeO) could also be used. Solid graphite was used as the moderator in the Chernobyl reactors; it stands to reason that solid graphite was used for slowing down fast neutrons in the reactor core. As experienced with the burning during the Chernobyl disaster, graphite burns at high temperatures if exposed to air.

BACKGROUND OF EXPERIMENT/TEST THAT LED TO THE ACCIDENT

It is reported that the Research Design Institute for Power Engineering in Moscow had identified a safety issue which had to do with outside power loss to the reactor and cooling. The basis of the concern is this: in the event of an off-site (outside) power failure, it would take two to three minutes to start the Emergency Core Cooling System (ECCS). The ECCS, which was dependent on emergency diesel generators, will take few minutes to come "online" so the engineers wanted to know (in the experiment) if the reactor's turbine would have enough residual energy to supply electricity to the plant equipment and maintain the coolant flow during those two to three minutes that the ECCS will be coming on line.

WAS THE EXPERIMENT/TEST NECESSARY?

It is important to understand that the Soviet Reactor Design, common with the rest of the world, is not only designed to withstand an accident but also to cope with loss of power simultaneously.

In an accident situation when the reactor is shut down right away, it means the reactor can't generate its own power so it will normally get power from external supply to the station or power from reactors at the same site. In order to ensure extra safety, a scenario of external power supply failure must be considered. The practice, therefore, is the provision of emergency diesel generators. The emergency diesel engines will usually get online in 30 to 60 seconds. The Soviets and for that matter the operators of the Chernobyl believed the time was not short enough and they wanted an almost uninterrupted power supply so they needed to have some power to occupy the seconds before the power from the diesel generators goes online. They decided to take advantage of the turbines because even when the reactor is shut down the turbines will continue to spin for a few seconds. They therefore decided to tap energy from the spinning turbine to generate electricity for the "delayed time" of the diesel generators. The experiment was specifically aimed at seeing how long the electricity from the "later" turbine spin would power the main pumps which keep the cooling water flowing over the fuel. The operators did start the test in unit 3 (Reactor 3) and did not have a major problem on the reactor but there was a sharp drop in voltage so they decided to repeat the test with unit 4 using much improved electrical equipment. The Chernobyl power station had 4 units/reactors. The test and subsequent accident happened with unit 4. The three remaining reactor units continued to operate for some years. Unit 2 shut down in 1991, unit 1 in 1996 and unit 3 in 2000. The decommissioning of units 1-3 was being carried out separately from that of the destroyed unit 4.

UNDERSTANDING THE GAS XENON IN NUCLEAR REACTOR OPERATION

The fission (splitting) of uranium (U-235) atoms in a reactor results in other smaller atoms referred to as daughter nuclides. Energy and more neutrons are produced and the reaction, which continues is referred to as chain reaction. The reaction cannot be left uncontrolled and controlling the reaction means controlling the number of neutrons (neutron flux). Control rods, made from neutron-absorbing material such as boron, hafnium, cadmium, etc., are used to control the reaction. Control rods are inserted into or removed from nuclear power reactor core in order to increase or decrease the reactivity of the reactor (increase or decrease the neutron flux).

Coming back to the fission, the daughters produced could also undergo changes (decay) to produce atoms that also behave differently. One of the "daughters" produced directly from fission is Xenon (Xenon-135). Another daughter is Iodine (Iodine-135). It is interesting to note that Iodine-135 undergoes changes and become Xenon-135, giving Xenon two sources in the reactor but a high percentage of the Xenon is produced from the Iodine-135. Xe-135 is a very powerful neutron absorber. In all reactors, a sudden reduction in power causes a quick buildup of xenon in the uranium fuel.

It means if the reactor is operating at low power (depending on how far the control rods are inserted) and there is high percentage of Xenon-135, the power will decrease further because of further absorption of neutrons by the Xenon. It would be obvious to any operator to raise the control rods in order to increase the power in a situation like that.

CHRONOLOGY OF THE CHERNOBYL ACCIDENT

The reactor (unit 4) was at full power at 1 a.m. on April 25, 1986 and operating normally; steam was going to the two turbines as expected and everything was normal. Permission was then given for gradual reduction of power for the experiment/test.

Within 12 hours (1:05 pm) the power had reduced to 50%. At 50% power, they needed only one turbine to take the steam from the reactor so one of the two turbines was switched off. Reduction of reactor power means reduction of electricity output so although the test was to be done at 30% power, the electricity distributor would not allow that. Consumers needed electricity! The operators were, therefore, forced to remain at 50% for 9 hours.

At 11:10 p.m. on April 25, the staff at Chernobyl got the "green light" to proceed with the reduction of power to 30%. The operator unfortunately forgot to reset a controller to hold the power at 30% and so the power fell to 1%, which was too low for the test. As explained earlier, sudden reduction in power would result in a fast buildup of xenon. If the reactor operation were in a steady state operation, xenon-135 will easily be "burned off" as quickly as it is created from decaying iodine-135, by absorbing neutrons from the ongoing chain reaction to become highly stable xenon-136. It means at that sudden change in power the production of Xe-135 from I-135 was faster that the "burning off" process because of lower neutron number (flux).

The low power also meant water was not boiling in the pressure tube as expected. In order to increase fission reaction and for that matter the power of the reactor, the operator pulled out almost all the control rods and even that could only raise the power to 7%, far below the level the experiment was to be done. The Xenon and water issue had conspired to let the reactor behave like a car whose accelerator is floored and the brakes on.

For the reactor design in question, pulling out that number of control rods is considered a very serious error due to the fact that some of the rods were used for emergency shutdown, and if they were all pulled out above the core, it took too long for them to fall back in an emergency situation. The Soviets were very firm on that safety point, and it was stated that "not even the Premier of the Soviet Union is authorized to run the reactor with less than 30 rods!" This notwithstanding, it has been widely reported that at the time of the accident there were about 8 rods in the core of the reactor.

Going back to the events, at 1 a.m. on April 26, 1986, the violation of the procedure on control rods could only bring the power up to 7% and because the plant was not intended to operate at that level, other problems would follow. Automatic controllers for control of water returning from the turbine were affected. The reactor became very unstable and was close to being shut down by emergency rod but the operator disabled emergency shutdown signals in order to avoid aborting the test.

By 1:22 a.m., the operators felt the test could start because things were stable. Interestingly, they would want to repeat the test, notwithstanding the problems they had encountered. If it were one test, then they would allow the reactor to automatically shut down once they disconnect the turbine, as would happen in the test. They, therefore, disabled a signal for automatic shutdown.

The turbine was disconnected as planned and the "slowing" turbine's energy fed to 4 pumps (out of the 8 main pumps). As the turbine slowed down, the pumps also slowed in pumping. The water in the core of the reactor, now moving more slowly over the hot fuel, began to boil; the power started rising slowly and faster in a few seconds. At this point an operator pushed the button to drive in the emergency rods in order to shut down the reactor. Within few seconds the power had risen perhaps beyond the reactor's full power. At about 1:24 a.m. the intense power surge would lead to excess steam in the reactor and intense pressure. The reactor fuel cell began to erupt, with possible build-up of hydrogen at that high temperature and pressure due to zirconium-steam reactions. The rupture of several fuel channels would increase the pressure in the reactor and eventually there was steam explosion, which lifted the concrete shield on top of the reactor, dispersing nuclear material into the atmosphere. The steam explosion was followed by a second explosion that resulted from the buildup of hydrogen.

There were also burning fragments of fuel and graphite thrown out in the explosion. The RBMK reactor did not have a containment vessel, and without that protection, radioactive material escaped into the wider environment.

RESPONSE AND IMMEDIATE EFFECTS

As the scale (the most serious accident in the history of the nuclear industry) of the accident became apparent, and the direction of the wind veered toward populated areas near the plant, the Soviets ordered first that people in Pripyat and other nearby towns stay indoors (to reduce their exposure to the radioactive cloud). A decision was then taken to evacuate them. On April 27, 45,000 people from Pripyat were evacuated, followed by evacuation of over 90,000 people living within 30 km of the plant. The authorities of the Soviet Union and, later, of the Commonwealth of Independent States (CIS) spent huge resources to deal with the consequences of the accident. Efforts were made to clean up contaminated areas and to reduce the amount of radioactivity in food and drink. Subsequently, a shelter was built to contain the damaged reactor.

The immediate brunt of the accident was, however, borne by emergency workers (including firefighters) and personnel that were on-site during the first days of the accident. No member of the public received immediate lethal doses of radiation. Two station staff were killed almost immediately. Twenty-nine others died over the following few weeks, many from severe skin damage. Others received high doses of radiation, with predicted future negative effects. As stated earlier, those who died and those who received high doses were staff of the plant and emergency workers, including fire fighters.

LESSONS LEARNT

In the aftermath of the Chernobyl accident, the Soviet Union looked at the flaws that led to the accident and identified several planned actions to improve the safety of RBMK type reactors. The safety issues were examined in two major perspectives, the human factor and design factor. As identified in the chronology of events, a lot of procedural, management and operator errors culminate in the accident, key among them being the decision to finish the safety-related test before the reactor was shut down. The Soviet Union initiated improved displays of information in the control room, improved operator training; improved procedures; and have made it much more difficult to disable safety systems.

With respect to design, changes were made to prevent a Chernobyl type accident occurring again. Fuel enrichment was increased in order to increase power and flux peaking over the entire range of reactor operation. The efficiency of the emergency stop system was increased by eliminating the initial increase in reactivity when engaged. Chernobyl's RBMK control rods take 18 to 20 seconds to insert. Eighteen (18) to 20 seconds is considered too long since the time it takes a reactor power excursion to cause damage is less than 10 seconds. The Soviet Union resorted to increasing the speed at which control rod insertion occurs. They also added a new 2.4 second shutdown system. The additional safety measures in the RBMK design made the reactor sufficiently safe but no RBMK reactors has since been built. A major safety design of reactors today is a secondary containment structure so the entire reactor core is located in the containment. In case of an accident, the containment vessel should reduce risk by preventing the risk of escaping radioactive material. In the case of the 1979 Three Mile Island accident in the USA, while the reactor was destroyed, radioactive materials were contained and there were no deaths or injuries. Modern reactors, unlike the RBMK reactor design, have containment vessel.