REACTOR PHYSICS BEHIND THE CHERNOBYL ACCIDENT

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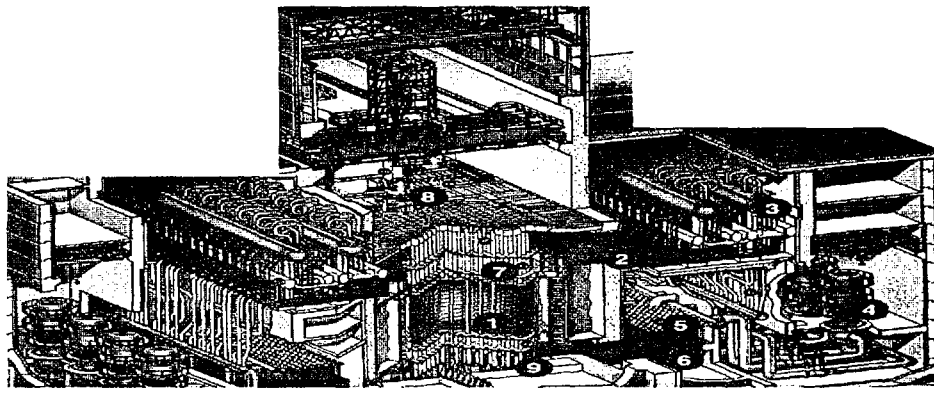
There are some fourteen Chernobyl type of power reactors (~1000 MWe) in operation at five different sites in Eastern Europe. In Russia; in St. Petersburg (4), in Smolensk (3), and in Kursk (4) in the Ukraine in Chernobyl (1) and in Lithuania in Ignalina (2). The oldest one is west of St. Petersburg and the most powerful one is in Ignalina. The reactors at St. Petersburg and in Lithuania are near to the Baltic sea.

An intricate reactor construction was the most important cause of the accident. There were other reasons too; human error, politics and economics.

A nuclear power reactor of Chernobyl type, RBMK is made up of uranium rods – enriched with a few percent of the fissionable U^{235} and the rest of the material is of the non fissionable U^{238} - placed in some 1600 vertical cooling channels surrounded by graphite blocks forming a 7 meter height 12meter diameter cylinder. The uranium fuel in the channels is cooled under 70 bars pressure of a mixture of boiling water and steam which is piped into four steam drums. From there, the steam is conveyed to the turbines and the water is pumped into the bottom of the cooling channels.



Neutrons with a speed of corresponding to 2MeV are produced in the U^{235} at the fission process and are slowed down to the speed corresponding to 0.02 eV in the graphite. Some of them are absorbed in the water and others are absorbed in the uranium there they split other U^{235} nuclei. When water is replaced by steam, fewer neutrons are absorbed in the coolant and more reach the fuel. The reactor power will increase. Reactors which increase their power when steam replaces water have a positive void coefficient. When the power

increases the fuel becomes hotter and in that the non fissionable but neutron absorbing U^{238}. U^{238} captures more neutrons at higher temperatures. The fuel's ability to absorb more neutrons without causing more fission at increasing temperature is characterized with the fuel's temperature coefficient, also called the fuel's Doppler coefficient. The fuel's temperature coefficient is always negative, the more negative the stronger dampening effect on power increase. Generally, the fuel's negative temperature coefficient has a stabilizing effect. During normal operation the power is regulated with neutron absorbing rods – control rods – which are lowered into the core from above.

The accident was preceded first by decreased and then increased reactor power. An unsuitable axial neutron flux distribution with an extremely accentuated peak at the lower part of the core as the result. The operating personal was unaware of this, due to deficient reactor instrumentation and training.

To study the plant's response to the loss of grid connection, an experiment was planned. As a preparation of the experiment the cold feed water to the steam drums was throttled. The suction lines of the main circulation pumps became filled with water which was almost at saturation temperature and therefore contained air bubbles. Cavitation started at the pumps. The experiment began with the disconnection of the plant from the external electrical power supply. The pumps' motors were supplied from the plant's retarding generator with declining voltage and frequency. The pumps' discharge pressure became degraded and the water flow to the channels decreased, the steam content in the channel increased dramatically. Possible leakage in the pipes below the reactor contributed to the increase of the steam content in the channels. The increased steam content in the reactor caused an avalanche like power increase. The mechanically maneuvered control rods could not break the runaway reactor. The fuel's temperature coefficient was not negative enough to be able to hinder the power increase. The temperature coefficient's absolute value is decreasing with increasing fuel temperature, therefore its damping effect is diminished at elevated fuel temperatures.

Du to the dramatically fast power increase the center of the fuel melted and partially evaporated, while the outer parts whose surface was in contact with the coolant remained solid. When the fuel reached melting temperature the power input continued and was used to supply the melting energy without increasing the fuel temperature similarly when the fuel temperature reached the vaporization temperature the increasing power input was used to vaporize the fuel without increasing temperature, in both cases no increased dampening effect was available from the fuel temperature coefficient. Du to the internal gas pressure the fuel exploded. Also chemical explosions has taken place. Steam explosion when the hot fuel and the burning graphite came in contact with the cooling water. Hydrogen was formed when the temperature of the fuel's zirconium cladding exceeded twelve hundred degree Celsius, hydrogen was produced also due to radiolyses. Also the hydrogen exploded at high temperature. The evaporated fuel was thermally lifted to some kilometers height, there it became condensed and formed particles. The particles were spread by the wind and landed with the rain also in far away countries. A great number of fuel fragments fall on the roof of the reactor building and into the surrounding environment. The core melt and debris is still remaining in the remnants of the reactor.

Since the accident the void coefficient was decreased by increasing the U^{235} enrichment of the fuel, the reactor instrumentation was improved, the speed of the control rods was increased and the knowledge of the personal concerning this type of reactor enhanced.

In the near future stability monitors should be introduced and the absolute value of the fuel temperature coefficient increased by introducing fuel rods with smaller diameter to increase the surface are/to mass ratio of the fuel.

To avoid the devastating international consequences of an other accident everything in the framework of reasonable costs should be accomplished as soon as possible.