

# Chernobyl

## Chernobyl Reactor Characteristics

- RBMK-1000 type Russian reactor (the initials stand for heterogeneous water-graphite channel-type reactor) with on-line refueling capability; the other Soviet reactor type is VVER pressurized water reactor (resembling Western designs)
- the RBMK design evolved from Russian defense reactors as a result of Russian inability in 1950's to manufacture pressure vessels; no Chernobyl type plants outside the Soviet Union; this reactor type could not be licensed in the U.S.
- graphite moderated, light-water cooled reactor; contains boron control rods; no containment structure; 2% enriched  $UO_2$ ; 1000 MWe; core height is 7 m and core diameter is 12.2 m; coolant pressure of 1000 psig and coolant outlet temperature of 545°F
- the reactor normally boils the water through fuel channels which are hollowed vertically through the graphite; the steam is fed to 4 separate steam drums located above and to either side of the reactor; 8 main circulation pumps are available but only 6 are required for normal operation
- separate cooling system used to cool graphite by circulating water down through control rod channels
- ECCS includes both passive and pumped water injection systems
- two primary contributing causes to the accident: (1) human judgment errors, and (2) fundamental design flaws (see list of 7 design flaws determined by EPRI staff)
- rx has positive void coefficient, relatively small fuel temp coefficient, and positive moderator temp coefficient
- has a built-in instability at low power, i.e., the power coefficient is positive at low power and high flow

## Chernobyl Unit #4 on April 26, 1986 at 1:23 am in Ukraine

- operating personnel were conducting unauthorized tests at 7% power to determine coastdown ability of turbine to provide power if the steam supply should be lost to the turbine; not only were the test procedures faulty but the operators even violated portions of the procedures
- the power level was dropped to 50% and allowed to stay there for  $\approx 10$  hrs due to grid demands; in the meantime, the Xe-135 (big  $\sigma_a$ ) concentration built-up to the point that the control rods were withdrawn even more to compensate for this
- the emergency core cooling system (ECCS) was disconnected for the test
- the reactor temperature/pressure was near saturation, coolant flow too high, rods withdrawn too far, feedwater supply overbalanced
- initiating event was closure of the emergency stop valve to the turbine
- flow reduction resulted in increased boiling in the core
- increased steam production caused positive reactivity feedback
- took about 2 sec for the reactor to go prompt critical, this first power/reactivity maximum was stopped by the Doppler effect
- a second peak ( $\approx 4500\%$  full power) was created by the lack of coolant flow; Doppler effect was of little help; reactor went superprompt critical again with the reaction being stopped by the fuel disintegration
- the pipes above the reactor were burst and the reactor building roof blown; steam explosion severely damaged the ECCS pipes above the core
- water removal did not result in moderator removal as in a U.S. light-water reactor (LWR) so there was no shutdown due to the loss of coolant
- water boiling away resulted in a reactivity increase (no absorber); thus reactor has a positive reactivity coefficient for loss of coolant (opposite of that for a LWR)
- reactor was on a super prompt critical excursion and went from 10% power to 4500% power over about 6 sec
- fuel cladding reacted with the steam to form hydrogen
- the hydrogen caused a secondary explosion whose energy release set the graphite core on fire
- a very severe graphite fire ensued
- this fire allowed radioactive particles to be carried away in a radioactive plume high into the atmosphere
- Chernobyl had no containment building as in the U.S. so radioactivity easily escapes
- operators had turned off 7 sets of emergency systems, any one of which could have prevented the accident
- reaction stopped by dumping 5,000 tons of boron-carbide, limestone and lead into the top of the reactor by helicopter
- in 1989 the World Association of Nuclear Operators was formed (similar to INPO after TMI-2)