



Special Safety Systems

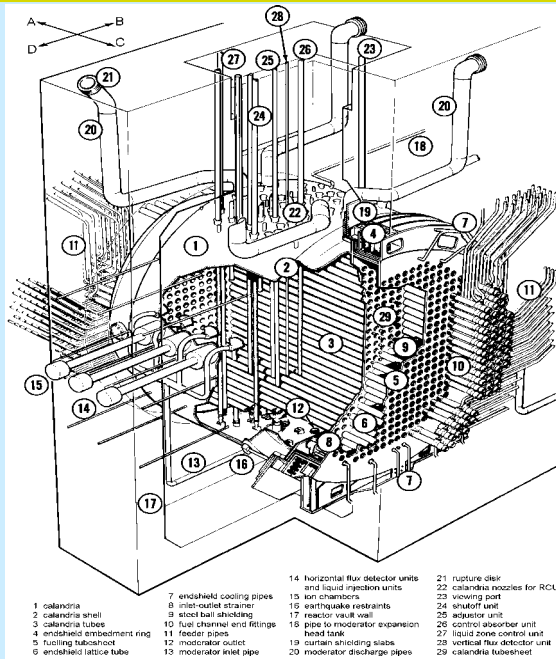
- **These are only for safety - they must not be used to help operate the plant**
- **They must be physically and functionally independent of process systems and of other special safety systems, they must be redundant, and they must be testable during operation**
- **Design basis must include control of radioactive material releases inside regulatory limits even after complete or partial failure of one of these systems to operate after a process system failure**

Slide 1

- The so-called Special Safety Systems consist of reactor shutdown (2 independent systems), emergency core cooling, and containment.
- Special Safety Systems are completely separate from the systems that operate the station. These are “poised”; that is, they are ready to operate at any time on demand. They are started by instrumentation which indicates the existence of abnormal plant conditions.
- The instrumentation systems (that measure pressure, temperature, flow, neutron flux, and so on) together define an “envelope” -- if the various plant conditions go beyond the envelope for any reason, three safety goals are applied:
 - **Shut off the Reactor** - quickly reduce fission heat production
 - **Cool the Fuel** - if the fuel is kept cool, it is not possible to risk the health of many people
 - **Close the Containment Openings** - if some radioactive material is released inside the station, the containment system will keep it from being released outside.
- Defence in Depth - if one of the Special Safety System does not work, the station is designed so that the other Special Safety Systems can limit the release of radioactive materials to small values.
- Testing - These systems do not work during normal operation, so that they must be tested regularly to be certain that they will operate if needed. The expected future unavailability must be less than regulatory limits.
- Some special safety systems need support services (electricity, cooling water, and so on). These support systems also must be tested to be certain that they are available.
- If a special safety system is not available, the station must be shut down for repair.



CANDU 6 Reactor Assembly



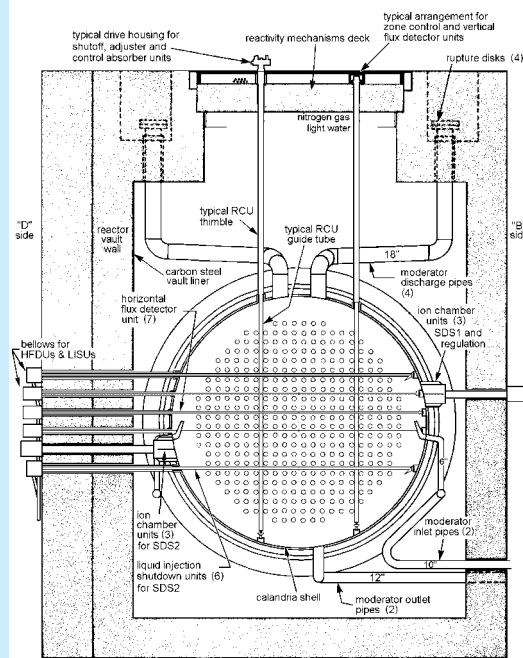
Slide 2

- This drawing shows the parts of a CANDU 6 reactor. Brief comments on each of these components.

1. calandria - this is a stainless steel tank full of heavy water
2. calandria shell - the cylindrical steel sheets which form the boundary of the calandria
3. calandria tubes - these tubes separate the cool calandria water from the hot pressure tube
4. endshield embedment ring - the ring attaching the calandria to the concrete vault
5. fueling tubesheet - the flat plate forming the outside of the calandria end shield
6. lattice tube - steel tube connects outside and inside tubesheets - end fitting inside each one
7. end shield cooling pipes - to remove heat from the end shield
8. inlet/outlet strainer - to prevent steel balls from entering cooling pipes
9. steel ball shielding - the main part of the end shield
10. fuel channel end fittings - to connect pressure tubes to feeder pipes and fueling opening
11. feeder pipes - to deliver and take away reactor coolant
12. moderator outlet - takes moderator water to heat exchanger for cooling
13. moderator inlet pipe - returns moderator water to calandria
14. horizontal flux detectors and liquid injection units - SDS2 systems for shutdown
15. ion chambers - low power and rate log instrumentation
16. earthquake restraints - to control movement of calandria in an earthquake
17. reactor vault wall - this vault is filled with ordinary water
18. pipe to moderator expansion head tank - to control moderator level, pressure
19. curtain shielding slabs - to protect vault wall concrete
20. moderator discharge pipes - if a fuel channel fails, these pipes relieve calandria pressure
21. rupture disk - breaks at a pressure slightly higher than atmospheric pressure
22. calandria nozzles for reactivity control units (RCU) - penetrations of calandria shell
23. viewing port - for viewing/inspection during reactor shutdown
24. shutoff unit - safety shutdown system SDS1
25. adjuster unit - control flux shape and provide for Xenon override
26. control absorber unit - rapid power reduction in abnormal conditions
27. liquid zone control unit - power and shape control under normal conditions
28. vertical flux detector unit - platinum or vanadium self-powered detectors
29. calandria tubesheet - the end boundary of the calandria, supporting the calandria tubes



Reactor End View

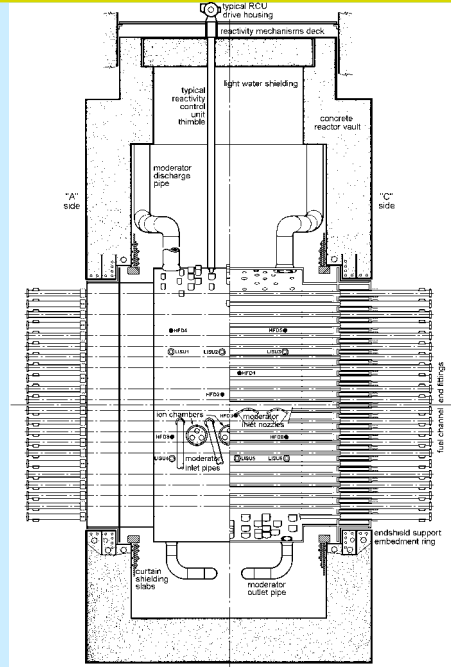


Slide 3

- This reactor end view shows the same components as the last drawing, but from a different direction.
- It should be noticed that the CANDU reactor is a big tank of water with a little bit of fuel in it. By comparison, the PWR is a small water tank with a large amount of fuel in it. This would make a big difference in serious accidents.
- The water-filled vault saves a lot of concrete shielding, and provides an easy method of cooling components outside the calandria shell.



Reactor Side View

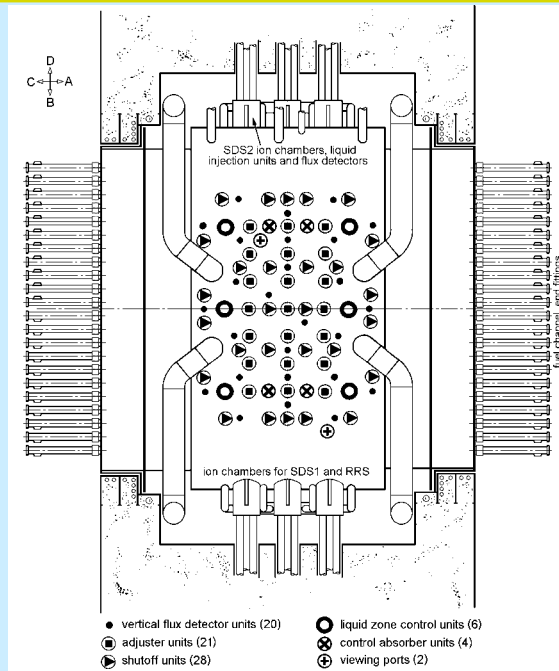


Slide 4

- Another view of the reactor, showing the arrangement of fuel channels and calandria inside the reactor vault.



Reactor Top View

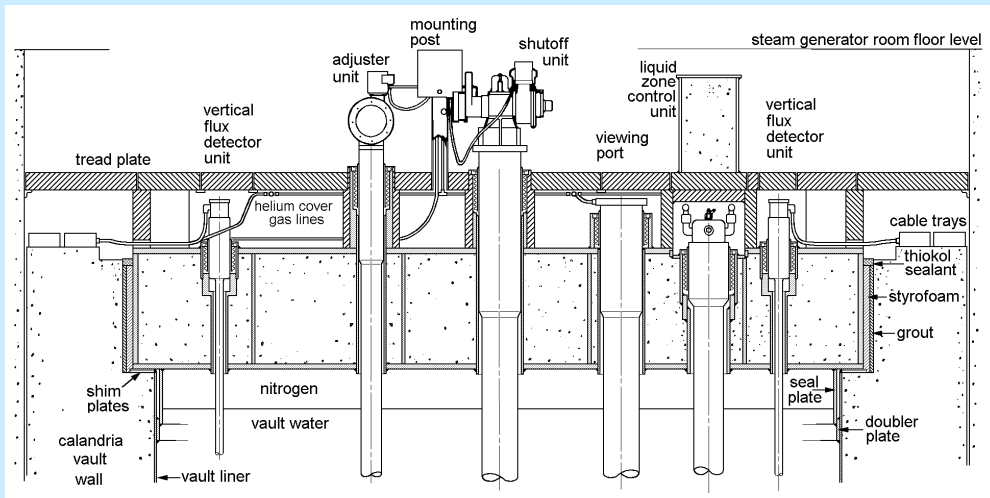


Slide 5

- This top view shows the location of the majority of the reactivity control units. These units pass between the calandria tubes from top to bottom of the calandria.
- All RCU's can be replaced during service. The vertical flux detectors can be replaced with the unit at full power.
- Some CANDU 6 units substitute Cobalt 59 rods in place of the normal steel adjuster rods. Cobalt 60 for medical purposes then can be produced in large quantities.



Reactivity Mechanisms Deck

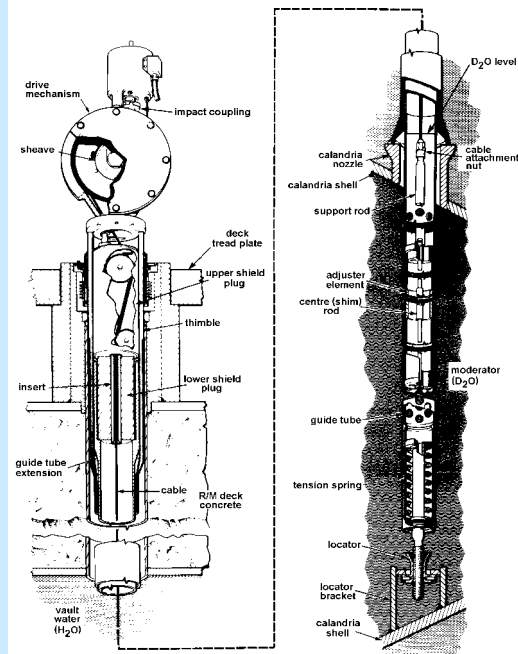


Slide 6

- The reactivity mechanism deck is accessible during operation. Operations which might be done are maintenance of a shutoff rod, rewiring or replacement of flux detectors, replacement of Cobalt rods with fresh rods, or several other inspection tasks.
- The diagram shows several plugs available for replacement of reactivity mechanisms.



Adjuster Rod Drive

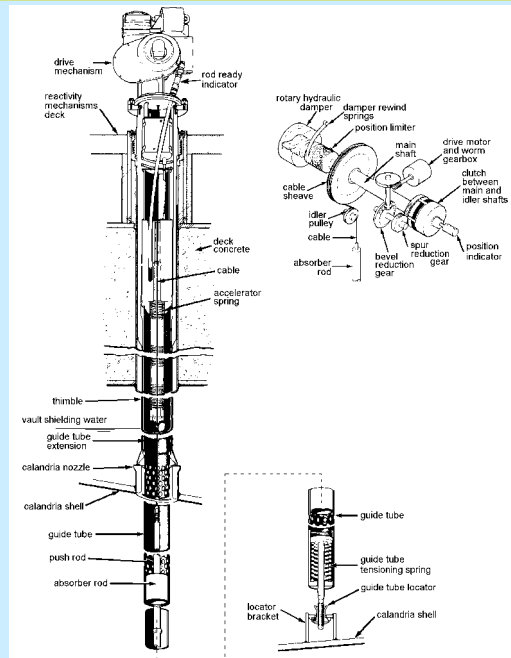


Slide 7

- The absorber material used in adjuster rods is normal stainless steel. Thickness is varied along the length to get the correct flux flattening. Rod length is varied according to the rod's radial position to achieve an approximately flat cylindrical core region. (Flattening is refined by appropriate fuel management patterns).
- The rods are suspended on a simple cable and are positioned by winding on a sheave. Shock absorbers are located at the bottom of each guide tube in case the cable breaks.
- Adjuster rods can be driven either out of or into the reactor by the reactor regulating system. They are driven in groups of two or four so that the neutron flux shape is maintained as well as possible.



Shutoff Rod

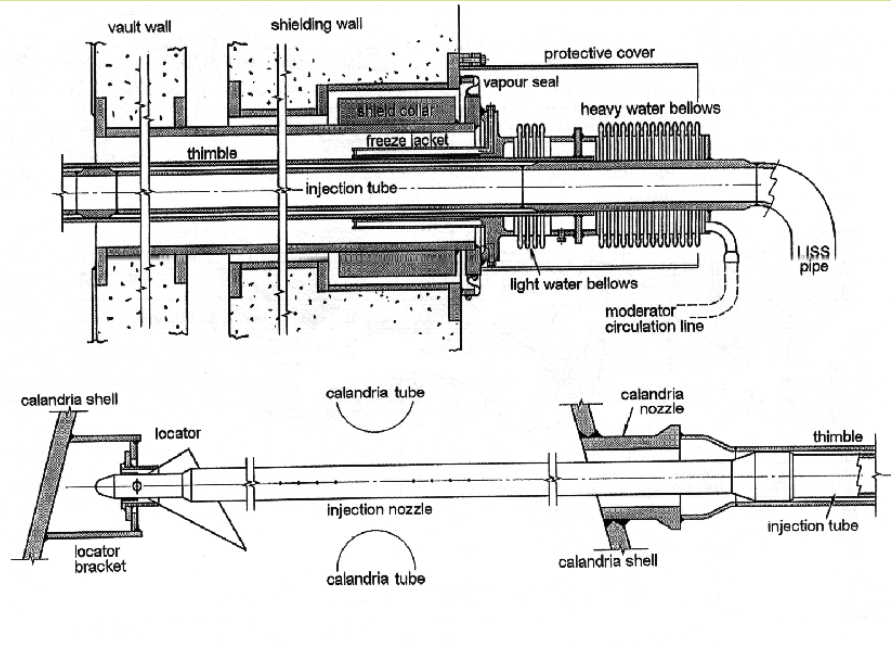


Slide 8

- Shutoff rods are basically of a “gravity drop” design. The first part of the drop is accelerated by a coil spring which is compressed when the rod is withdrawn.
- The rod drive is of the “drive out, drop in” type. Normally, an electric clutch holds the rod in a full-out position. This clutch is energized by the safety circuits associated with SDS1. A two-out-of-three voting logic is used to de-energize the clutch and drop the rod -- all 28 rods are dropped at the same time.
- Rod drop times are about 2 seconds to full in position. More importantly, the first reactivity reduction occurs in 0.6 to 0.7 seconds after loss of the clutch voltage.
- Rod drop speed can be measured with the reactor at full power -- as required by the licence conditions. Rod are dropped one at a time; then the clutch of the dropped rod is re-energized automatically to arrest its drop. The effect on system reactivity can be measured by the response of the reactor regulating system to the rod tip entering the reactor.



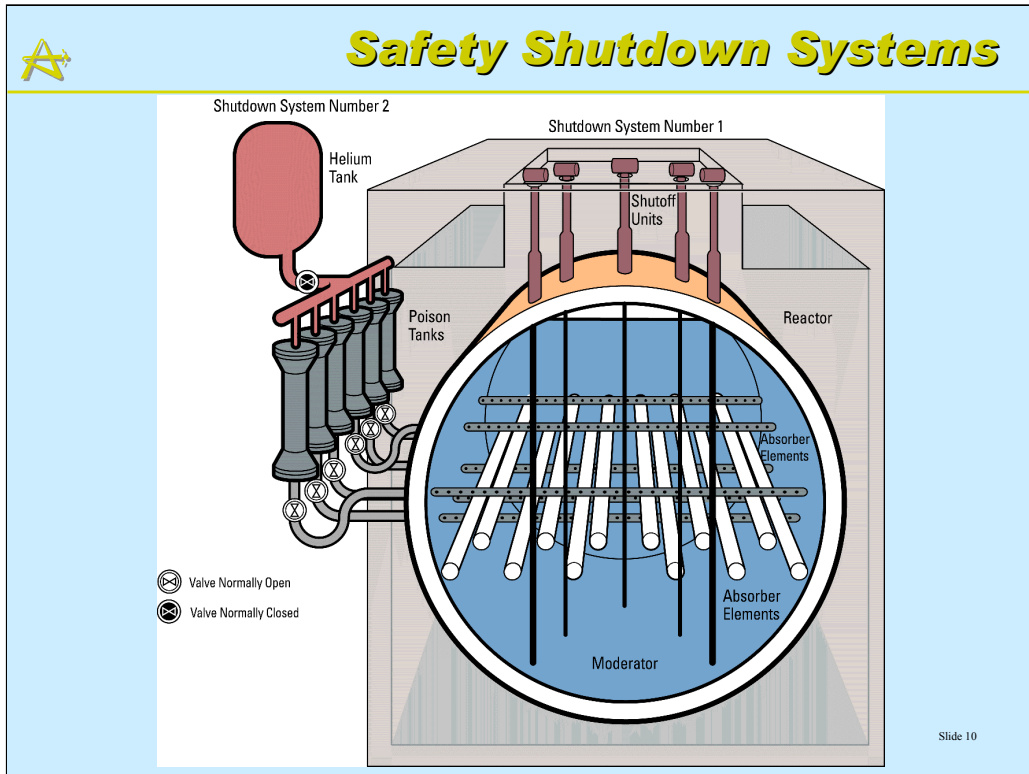
Liquid Poison Injection Tube



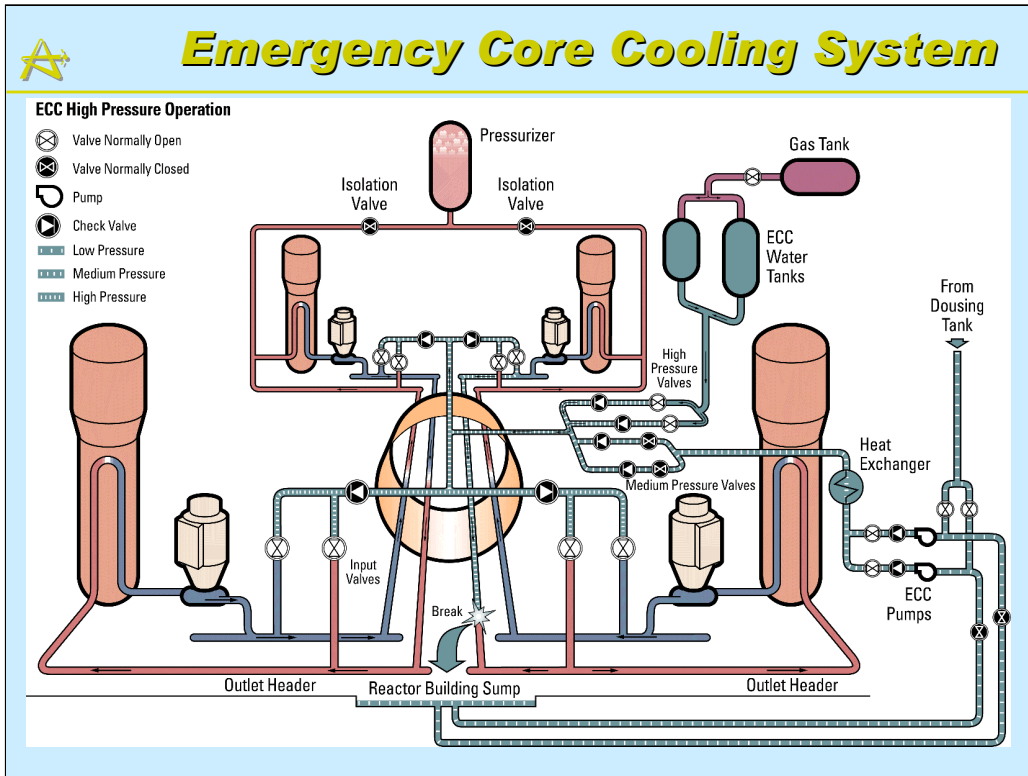
- This diagram shows the geometry of the gadolinium nitrate injection nozzle used in shutdown system number 2 (SDS2).
- Four rows of small-diameter holes oriented at a 45 degree angle to the vertical are spaced along the injection tube. The poison solution is forced out of the holes by high-pressure helium gas.
- The first negative reactivity effect occurs about 0.6 seconds after gas pressure is applied, and full negative reactivity is achieved after about 2 seconds. This system has a very large total effect of about -30% delta k.
- In the long term, the effectiveness of this system depends on the pH of the moderator water. Normally, the pH is about 6.0. If it rises above about 7 or 8, gadolinium will precipitate and reduce the amount in solution.
- SDS2 testing includes testing of the detector and trip logic chains, injection valve speed testing, and regular testing of the concentration and isotopic composition of the dissolved gadolinium in the poison tanks.
- Full injection tests are carried out at regular intervals (as are full SDS1 rod drop tests) in order to be sure that the overall system is working. In-core flux detector readings are compared with 3-dimensional transient flux calculations to verify that the calculation agrees with the real situation.



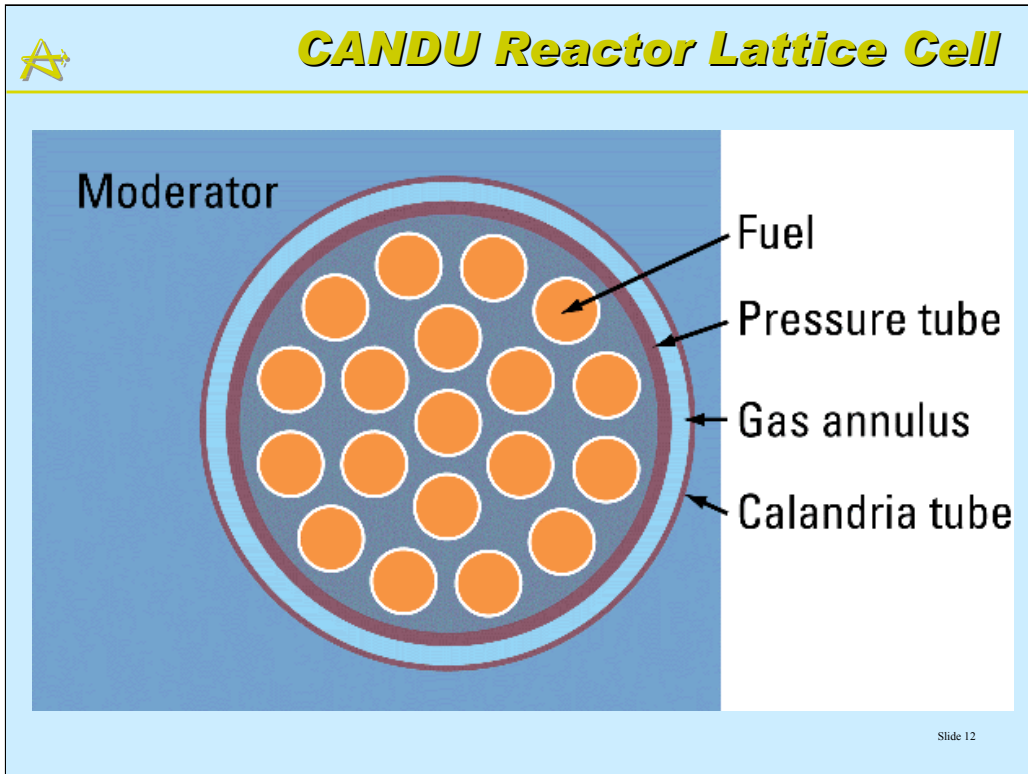
Safety Shutdown Systems



- This shows the general arrangement of SDS1 and SDS2. It can be seen that the two safety shutdown systems are different in concept, that they are located in different areas of the reactor building, and that they have the potential of being free from both common cause and common mode failures.
- To further ensure this independence, these two systems have completely separate initiation instruments -- produced by different manufactureres -- and their performance is maintained by two different groups of station staff.
- This high degree of separation is made possible by the large size and easy accessibility of the CANDU reactor system.



- Emergency core cooling is complicated for several reasons:
 - the anticipated accident might occur at any place in the HT piping
 - the pipe break might be of any size up to the diameter of the largest pipe
 - detection systems must be highly reliable
 - decay heat must be removed to keep water temperature controlled
 - the system is required to operate for a very long time -- until repairs are made
 - the system requires electricity, cooling water, and instrumentation supplies
 - the containment capacity for holding injection water is limited, so that recirculation is essential
- The CANDU 6 design uses gas-driven accumulator tanks followed by pumps to provide emergency core cooling. These pumps are first supplied with dousing water and then by water recovered from the reactor building floor.
- The two HT loops are isolated on a loss of coolant accident (LOCA) signal. In addition, steam generators are rapidly cooled in order to depressurize the HT system.
- Class III power is provided to pumps and cooling water systems. Heat is removed by RCW-cooled heat exchangers in the recovery pump circuit.



- From this view of a cross-section of the CANDU fuel channel, it can be seen that the hot fuel is very close to the cool moderator water.
- If the emergency core cooling does not work it becomes necessary to understand what will happen next in this core geometry, which is entirely different from the PWR geometry.
- Many experiments, done over the past 20 years, show that this extreme accident situation is controlled inherently by this geometry. With no water in the channel, the decay heat raises the pressure tube temperature until it expands and touches the calandria tube. Heat then is transferred to the moderator water at a rate which guarantees that no fuel melting occurs.
- Severe accidents in CANDU are, therefore, not so severe as they are in the PWR. It has been shown that controlled conditions can be maintained even under more severe conditions than this.

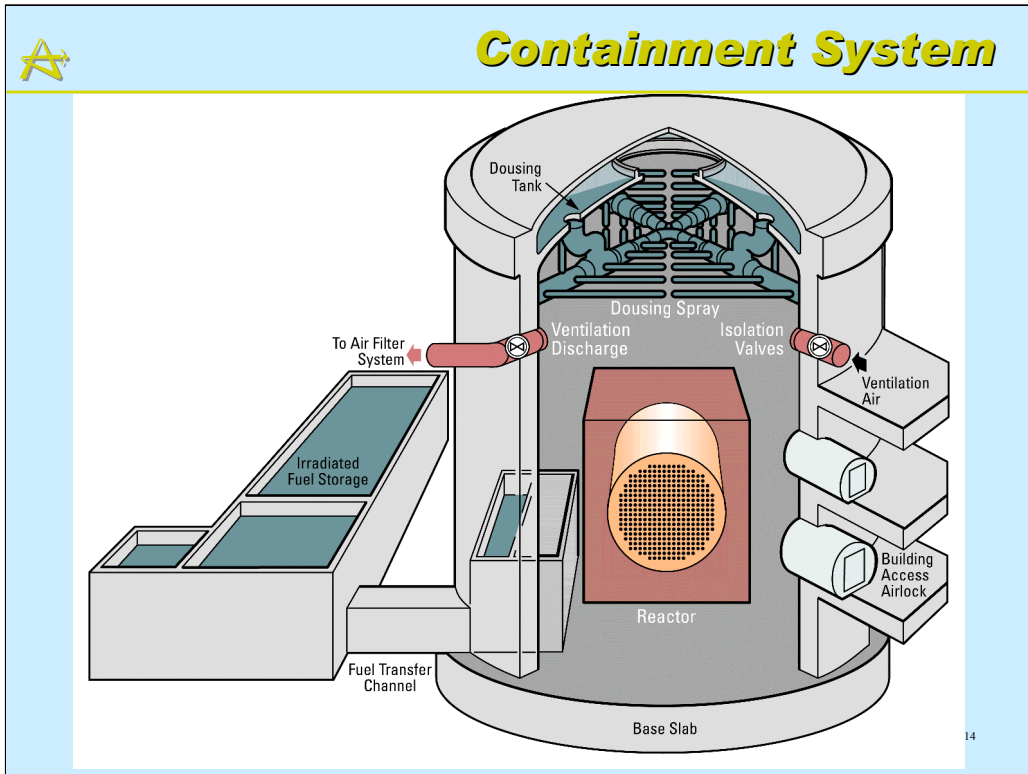


Containment Construction Opening



Slide 13

- This picture indicates the size of the CANDU 6 containment building. The wall of this building is approximately 1 metre thick, and it is heavily reinforced with steel bars. It is post-tensioned after construction by a network of steel cables, so that the concrete remains in compression up to the building design pressure and beyond.
- The design concept of this design is of the 'pressure-suppression' type. If steam pressure rises inside the building, an automatic dousing system is actuated to reduce pressure, and therefore stress, on this building.
- The low leakage from this building is tested at full design pressure at about ten-year intervals. In between these tests, the building integrity is tested during reactor operation, using a semi-automatic system installed in the station.
- The construction opening shown here is closed, of course, before reactor operation starts.



- This diagram shows the main subsystems included in the containment system.
- It should be remembered that the functions of the containment system are:
 - to seal openings quickly and reliably after an accident signal,
 - to maintain low-leakage performance at full design pressure in the short term,
 - to remove volatile gases, especially hydrogen produced during an accident in the short term and the long term,
 - to maintain chemistry control in the long term to keep radioactive materials from staying in the gas phase,
 - and to remove reactor decay heat produced after shutdown.
- Building isolation is actuated on either high radiation or high pressure, to close building ventilation dampers.
- Dousing water is supplied automatically to the building, on a high building pressure signal.
- Igniters and self-actuated recombiners remove any hydrogen in the building atmosphere.
- Heat is removed from the building by air coolers and ECC heat exchangers.