CANDU Safety
#7 - Emergency Core Cooling

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Safety Requirements

- for small LOCA
  - 720 feeders, 2 per channel, safety & economic requirements
  - prevent fuel cladding failure
- for large LOCA
  - safety requirements only
  - limit fuel damage so that:
    - fuel geometry in channel is coolable
    - public dose limits are met
  - prevent pressure tube failure

What and Where to Inject

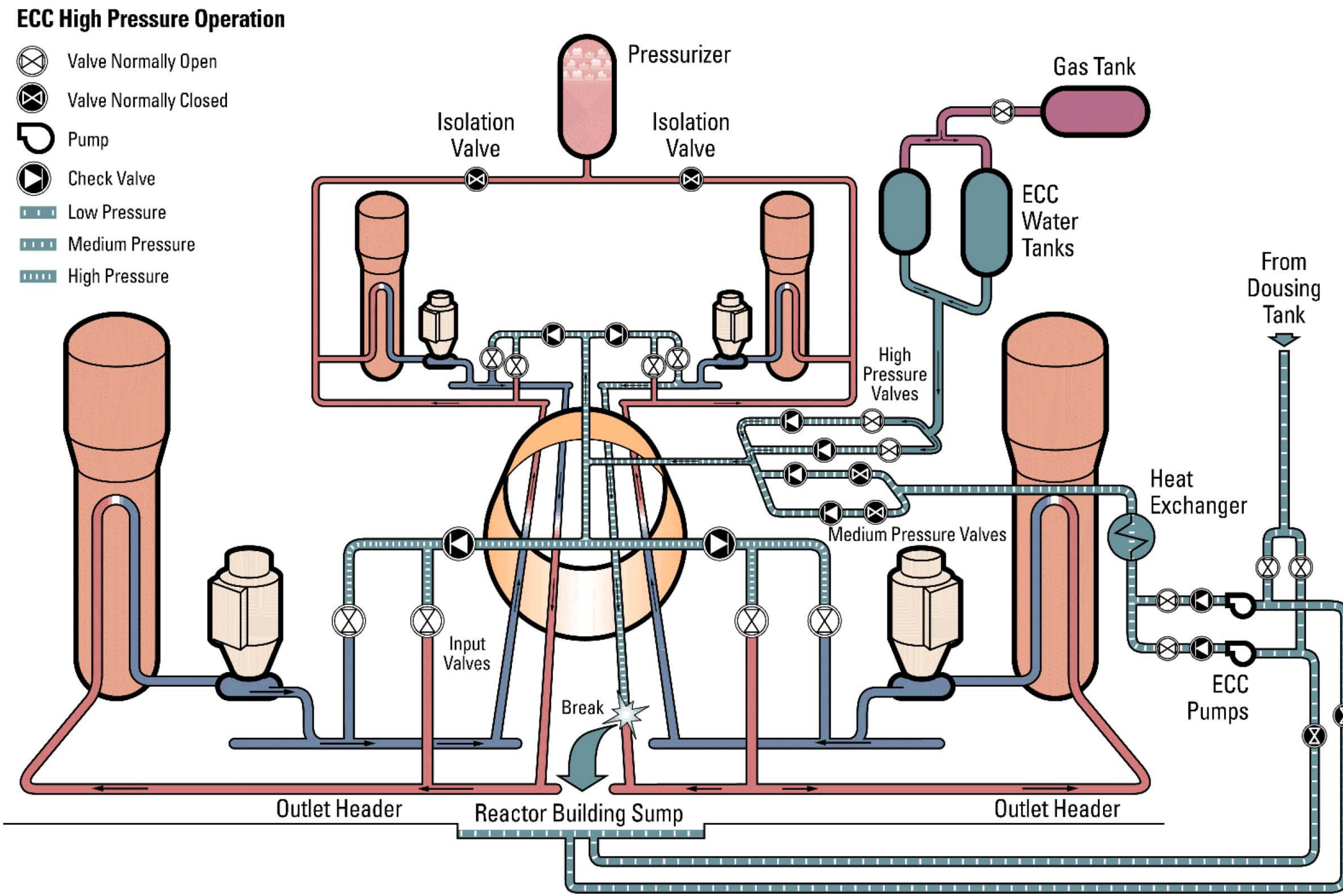
- CANDU ECC injects cold light water into the Heat Transport System
- goes into collectors (headers) above the core to which each fuel channel is connected by 2 feeders
- inject into all 4 headers in each loop, regardless of break
- can detect break, or break end, location and inject away from the break (Douglas Point, Indian designs) but modern CANDUs use all-point injection and allow for wasted water
- the injection point near the break will waste water; flow is sufficient that it does not harm ECC effectiveness

Comparison to LWRs

- economic concern on spurious injection
  - separate coolant and ECC by parallel/series valves, check valves & rupture disks to avoid downgrading heavy water
- LWRs
  - pour water into a large-diameter pot (but *borated)*
  - fill it up from the bottom and let steam out the top
  - core bypass via the shroud must be considered
- CANDU
  - fill each horizontal channel from either end, *ordinary water*
  - must remove stored heat in feeders to get water in
  - steam exits up the feeders as water comes in

Injection Pressure

- three phases of injection: high pressure, medium pressure, recovery
- triggered by low heat transport system pressure plus a conditioning signal (e.g., high building pressure)
- high injection pressure (4.14 MPa) set by:
  - avoidance of fuel sheath dryout for small breaks
  - fast refill for large breaks to remove stored heat from feeders and create a large channel pressure drop
- high pressure phase: 2 water accumulators (tanks) driven by high-pressure gas
- large volume: 200m^3 or same volume as heat transport system



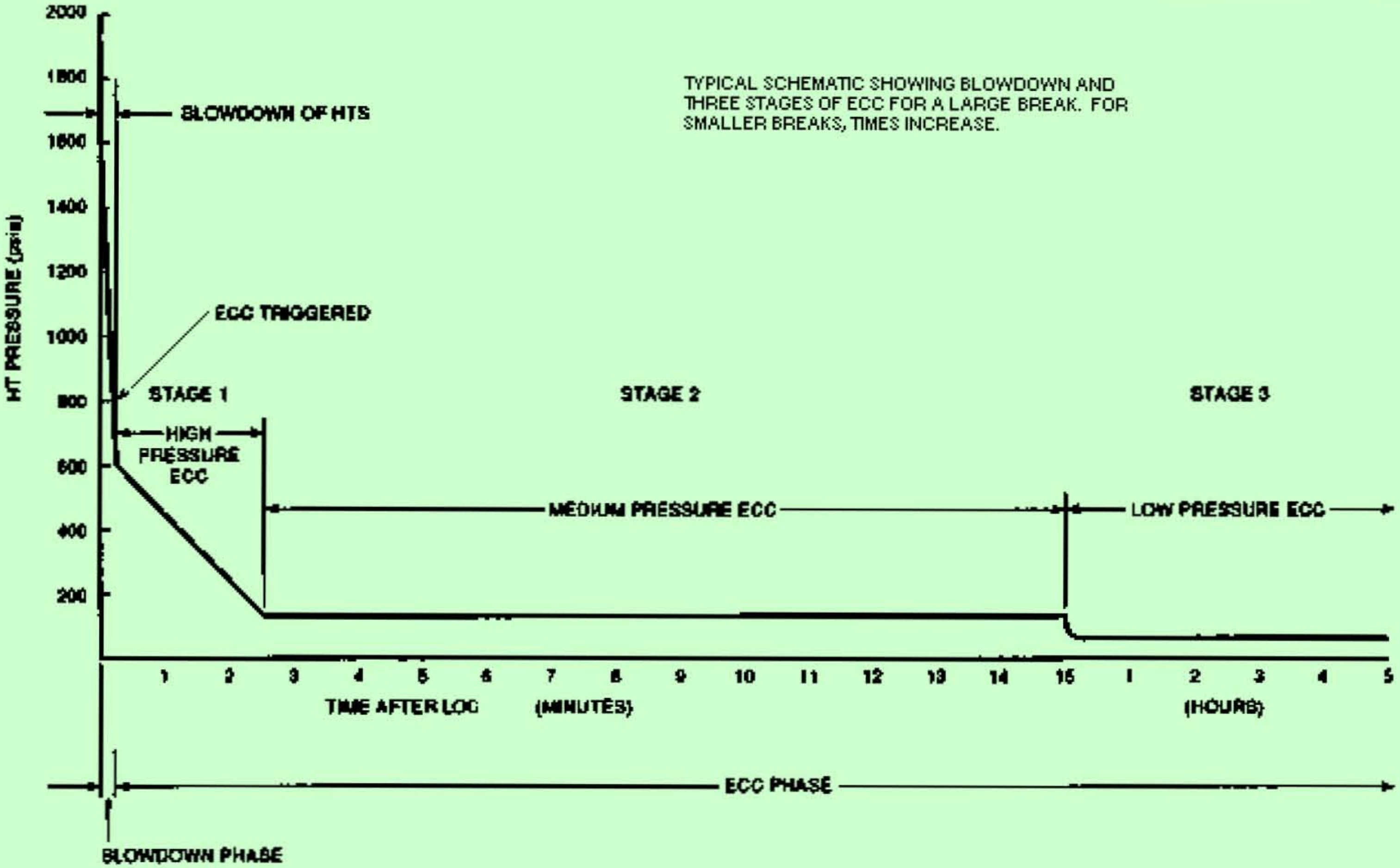
ECC High Pressure Operation
Valve Normally Open
Valve Normally Closed
Pump
Check Valve
Low Pressure
Medium Pressure
High Pressure
Pressurizer
Isolation Valve
Isolation Valve
Gas Tank
ECC Water Tanks
From Dousing Tank
High Pressure Valves
Heat Exchanger
Medium Pressure Valves
Input Valves
Break
ECC Pumps
Outlet Header
Reactor Building Sump
Outlet Header

Medium Pressure Injection

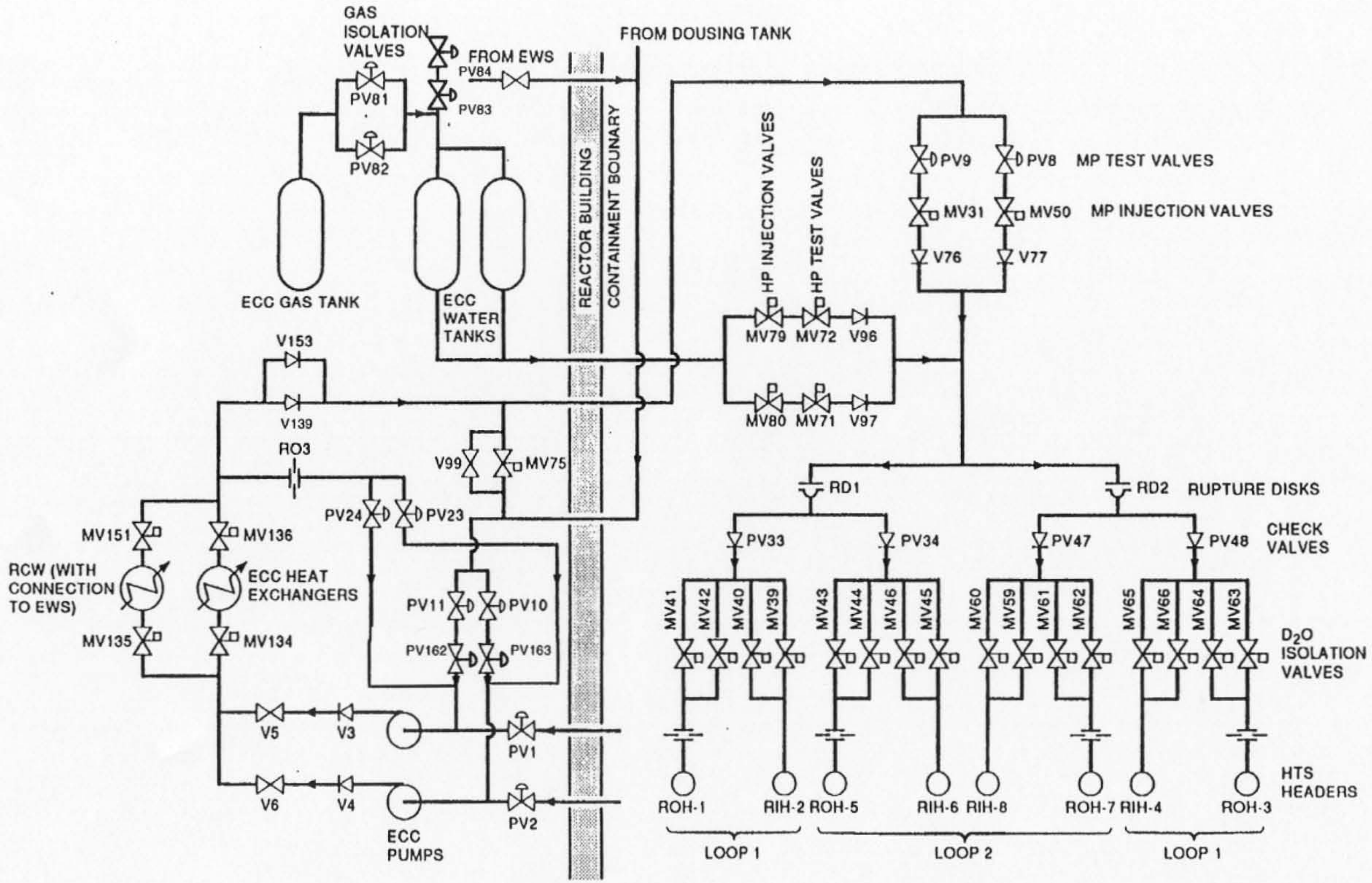
- pumped phase takes cold water from dousing tank and injects into headers
- 2 × 100% pumps powered by Class III and backed up by seismically qualified power (Emergency Power System, EPS)
- ensures there is a sufficient supply of cool water in the reactor building sumps before recovery mode starts
- maximum pressure: 1 MPa
- maximum flow: 600 l/s

Recovery

- same pumps recover water from the sump, pump it through heat exchangers, and return it to the heat transport system
- all phases fully automatic
- typical duration:
  - high pressure
    - 2.5 minutes for large LOCA
    - 45 minutes or more for small LOCA
  - medium pressure
    - 13 minutes or more
  - recovery
    - several months



Blowdown and ECC Pressure Curve Schematic

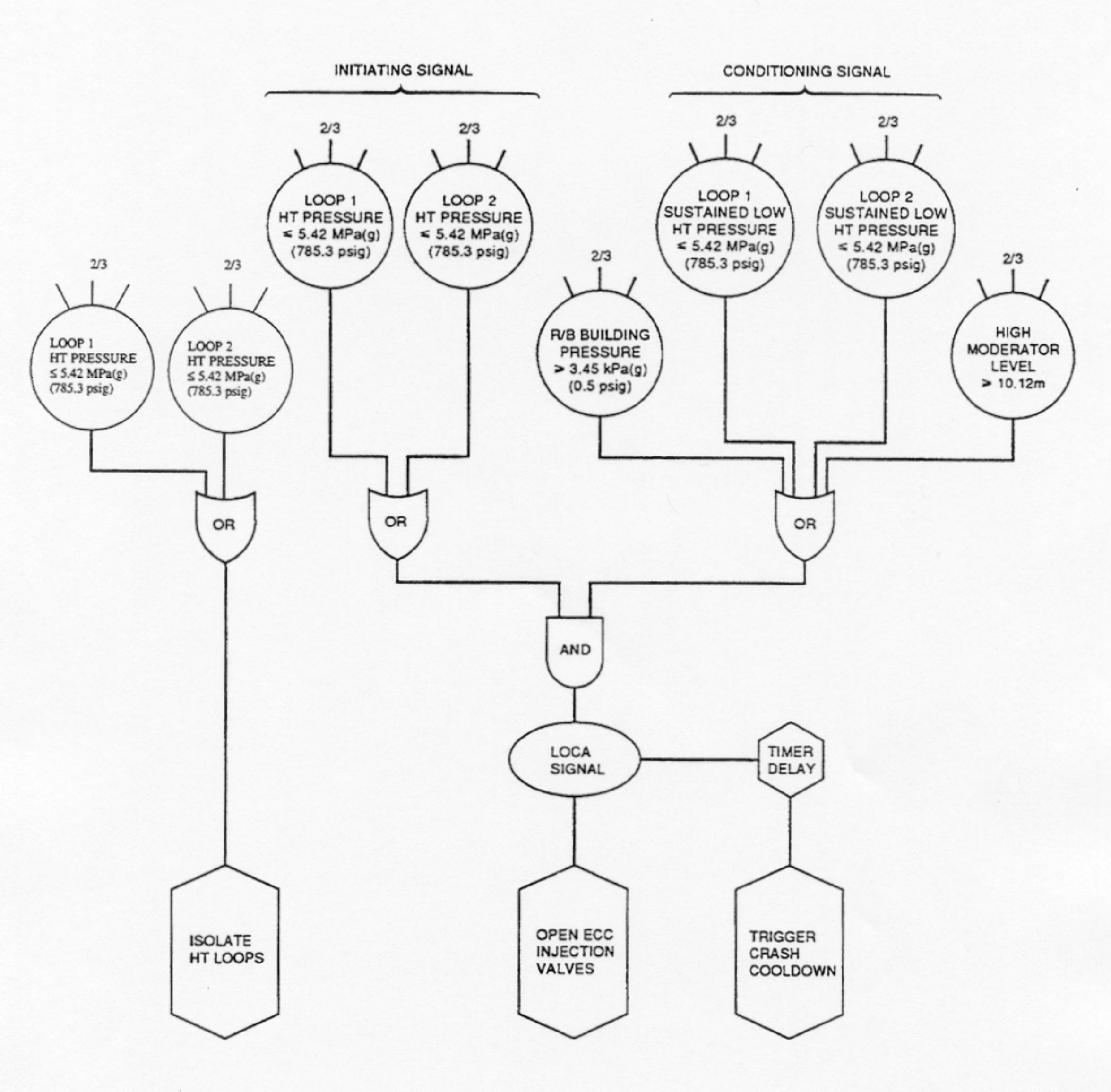


GAS ISOLATION VALVES
FROM EWS
PV84
PV81
PV83
PV82
FROM DOUSING TANK
ECC GAS TANK
ECC WATER TANKS
REACTOR BUILDING
CONTAINMENT BOUNARY
HP INJECTION VALVES
HP TEST VALVES
PV9
PV8
MP TEST VALVES
MV31
MV50
MP INJECTION VALVES
V76
V77
MV79
MV72
V96
MV80
MV71
V97
V153
V139
RO3
V99
MV75
PV24
PV23
RD1
RD2
RUPTURE DISKS
MV151
MV136
PV33
PV34
PV47
PV48
CHECK VALVES
RCW (WITH CONNECTION TO EWS)
ECC HEAT EXCHANGERS
PV11
PV10
MV41
MV42
MV40
MV39
MV43
MV44
MV46
MV45
MV60
MV59
MV61
MV62
MV65
MV66
MV64
MV63
D_2O ISOLATION VALVES
MV135
MV134
PV162
PV163
V5
V3
PV1
V6
V4
PV2
ECC PUMPS
HTS HEADERS
ROH-1
RIH-2
ROH-5
RIH-6
RIH-8
ROH-7
RIH-4
ROH-3
LOOP 1
LOOP 2
LOOP 1

Other ECC Functions

- rapid boiler cooldown
  - ensures ECC injection is not blocked for small breaks
  - ensures eventual refill of unfailed loop
  - some CANDUs (Darlington) use high-pressure pumps for small LOCA
- loop isolation
  - the two heat transport system loops are connected only through pressurizer, purification lines and smaller lines
  - CANDU 6: loops isolated on a LOCA
  - for LOCA + LOECC, half the hydrogen in containment
  - other CANDUs have one loop and design for it

Logic for ECC Functions



Unfailed Loop

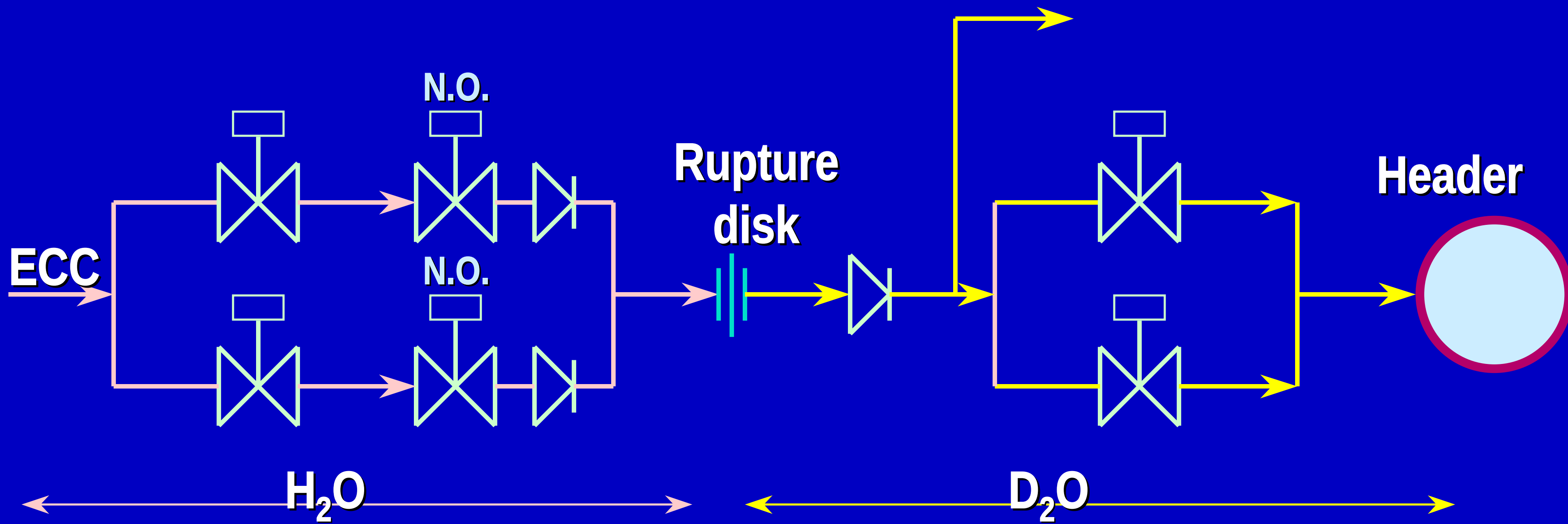
- if loops are isolated, most of the initial ECC flow goes to the broken loop
- unfailed loop loses about 20% of the inventory before isolation, and shrinks during steam generator cooldown
- fuel is cooled by flow from main heat transport system pumps or by natural circulation to steam generators
- in the long run, will be refilled by ECC

Heat Transport System Pumps

- pumps are *not* deliberately tripped at first since they assist refill by providing a strong core pressure-drop
- protects plant better for small LOCA (larger flows)
- pumps are therefore LOCA-qualified
- they are tripped after refill to avoid cold cavitation
- safety analysis is also done assuming Loss of Class IV power at reactor trip (pumps tripped off)
- contrast to approach followed in LWRs where pumps are tripped even for small LOCA

Reliability

- since ECC is a special safety system, it must meet the unavailability target of 10^{-3} years/year, or < 8 hours/year
- any valve can be opened for test without firing ECC



Summary

- **3 stages of ECC: high pressure, medium pressure, recovery**
- **fast refill for large breaks and prevention of economic loss for small breaks sets the design**
- **fairly complex valveing to meet reliability and testability requirements and reduce chance of spurious injection**
- **designed and tested to safety system unavailability requirements (< 8 hours / year)**
- **other actions: loop isolation, crash cooldown**
- **unfailed loop refilled in longer term**
- **fully automated**