Thermal Hydraulic Design Requirements in Safety Analysis: Transients & Accidents

Course 22.39, Lecture 4

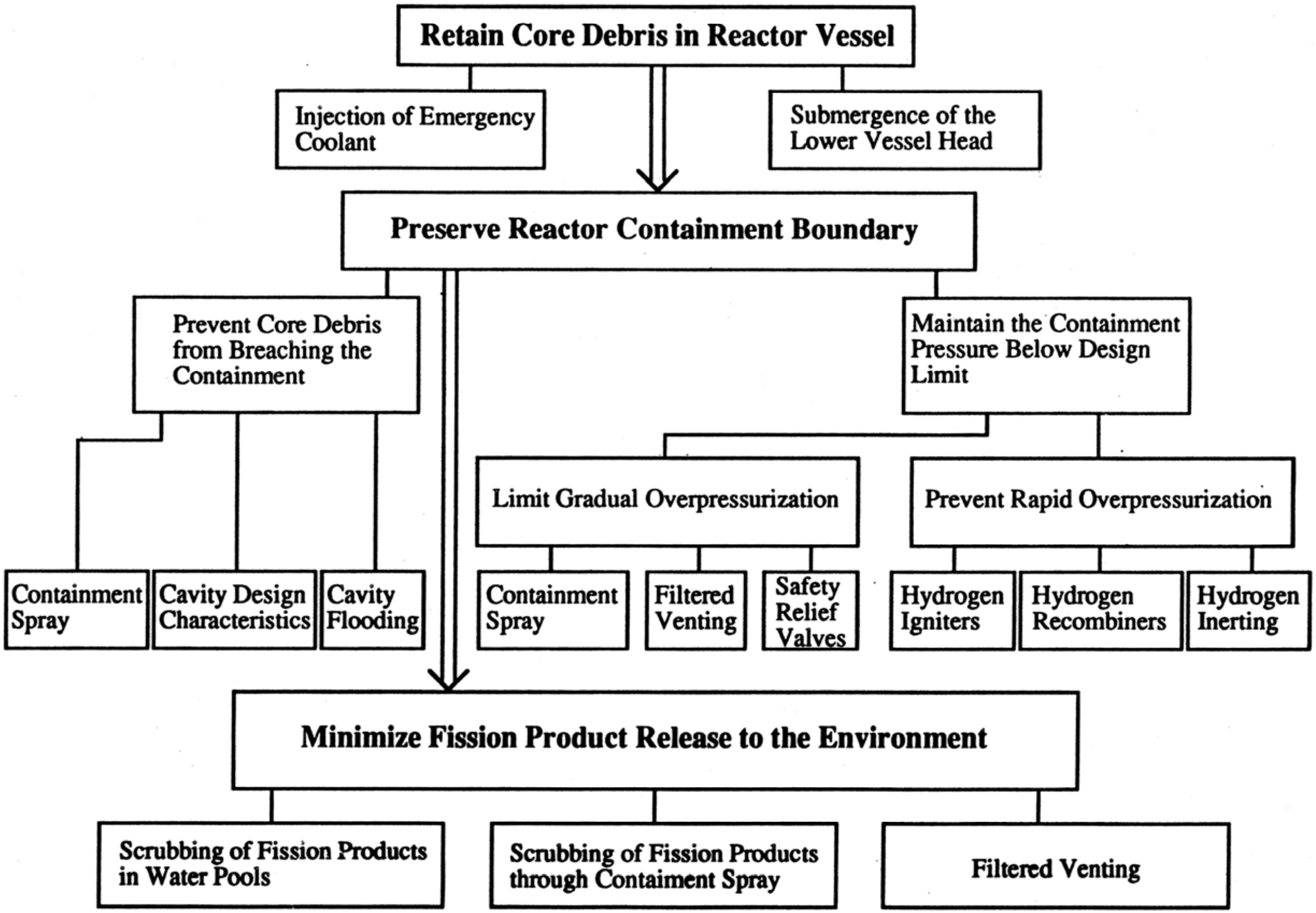
9/18/06

Professor Neil Todreas

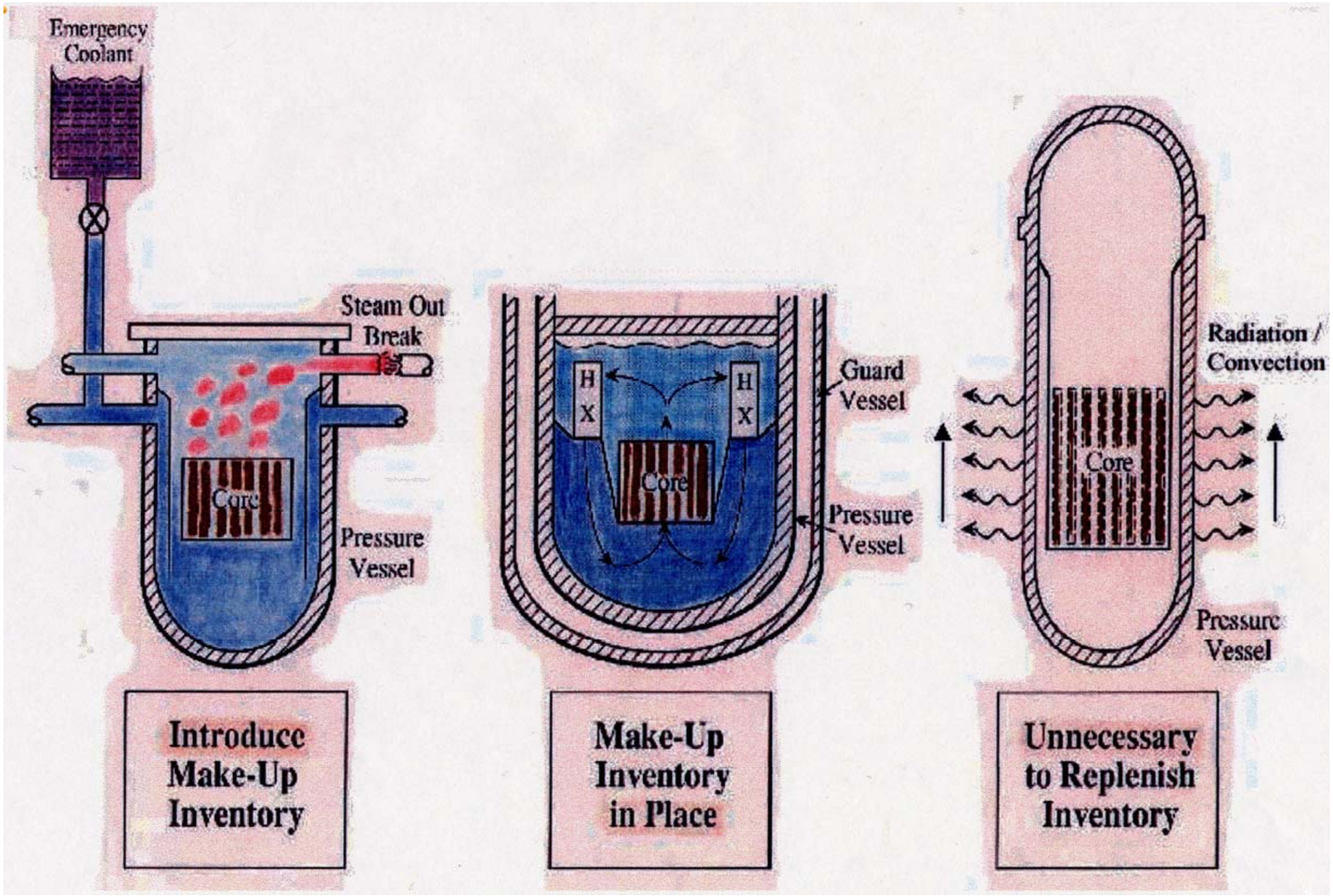
Reactor Safety Fundamentals

		Safety Elements		
		Design	Material Condition	People
Safety Functions	Nuclear (Reactivity) Excursion	RBMK		
	Fuel Overheating			TMI-2
	Decay Heat Removal			

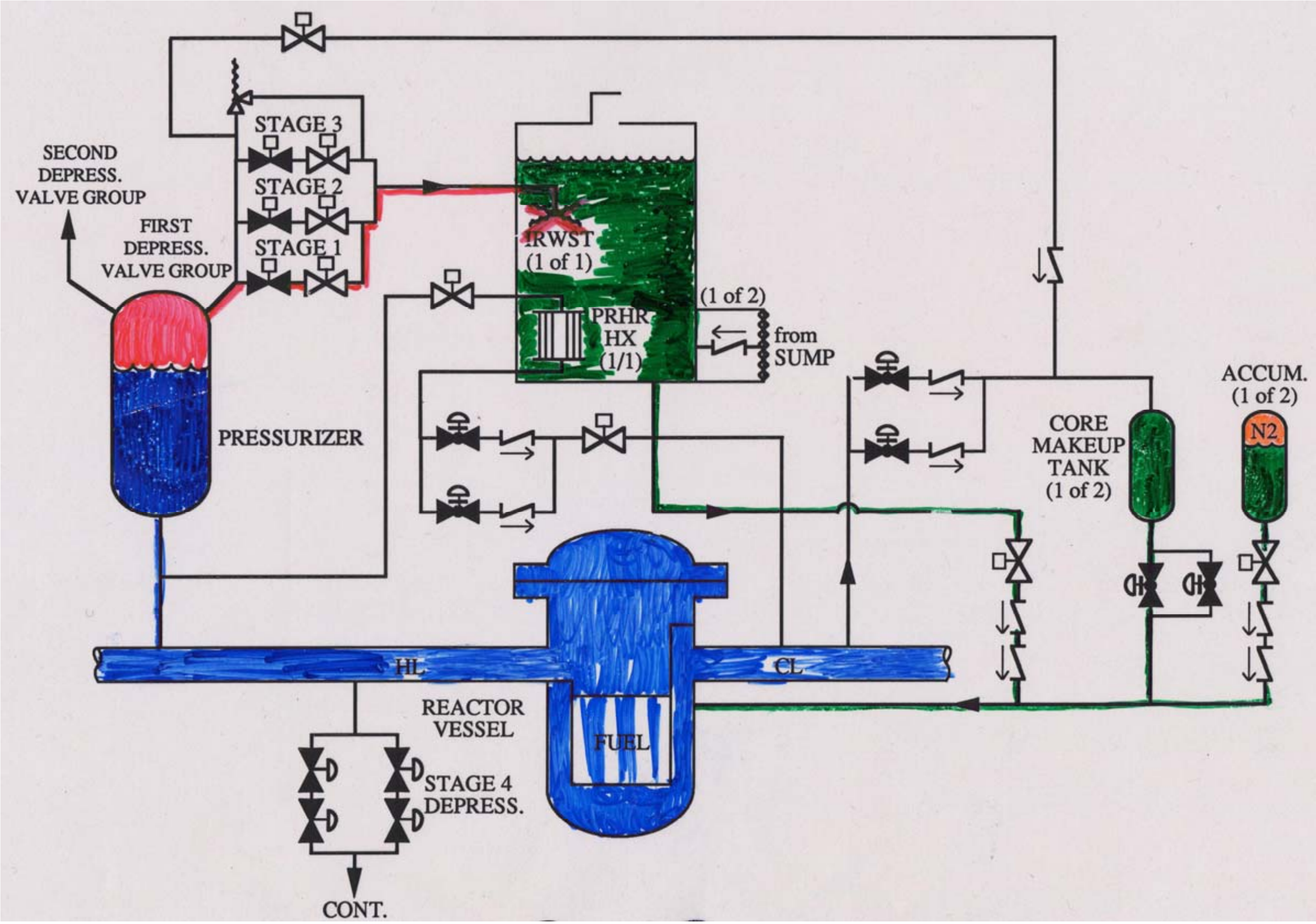
Goal: Prevent Fission Product Release to the Environment



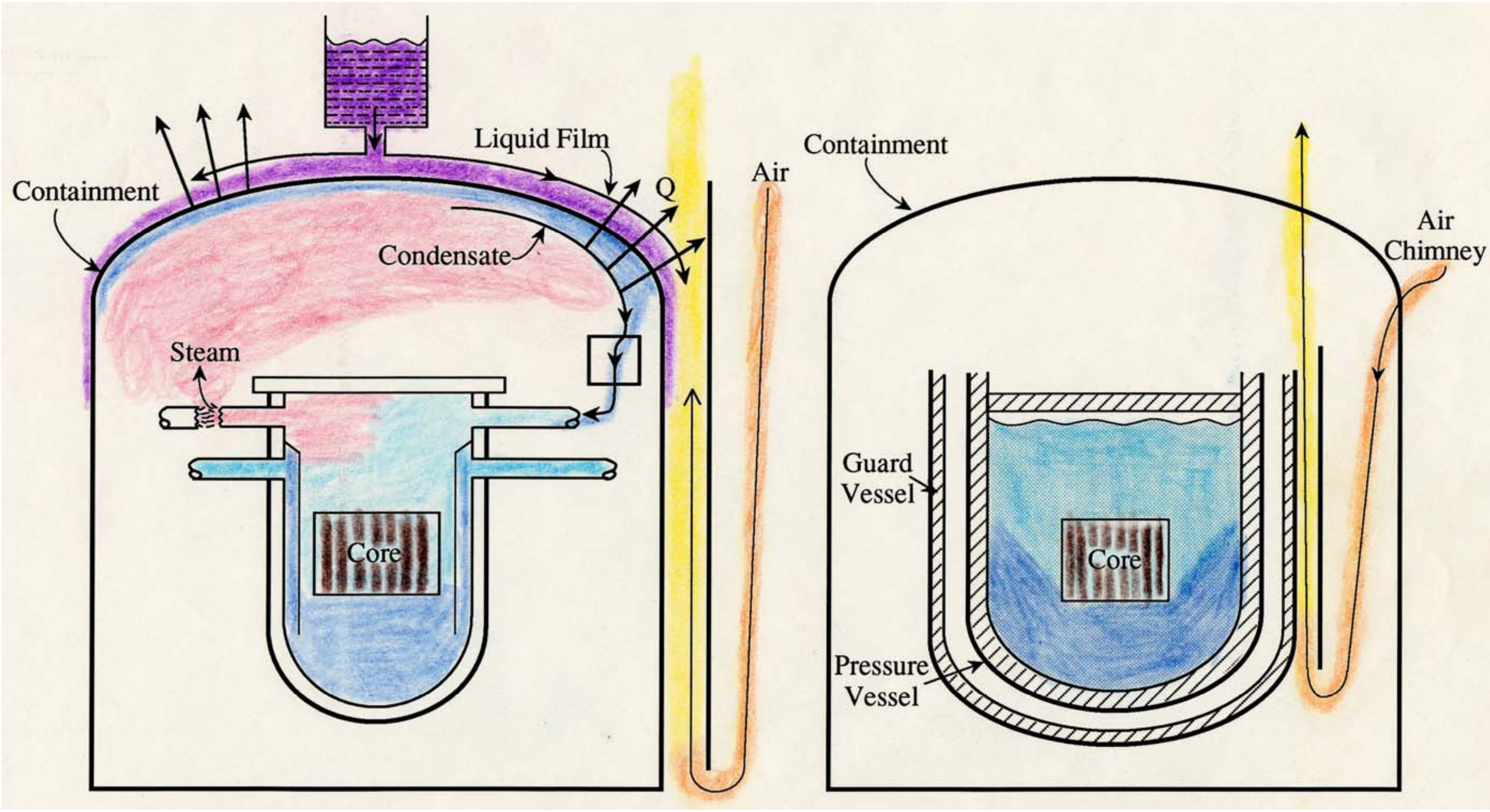
Concepts to Insure Core Cooling

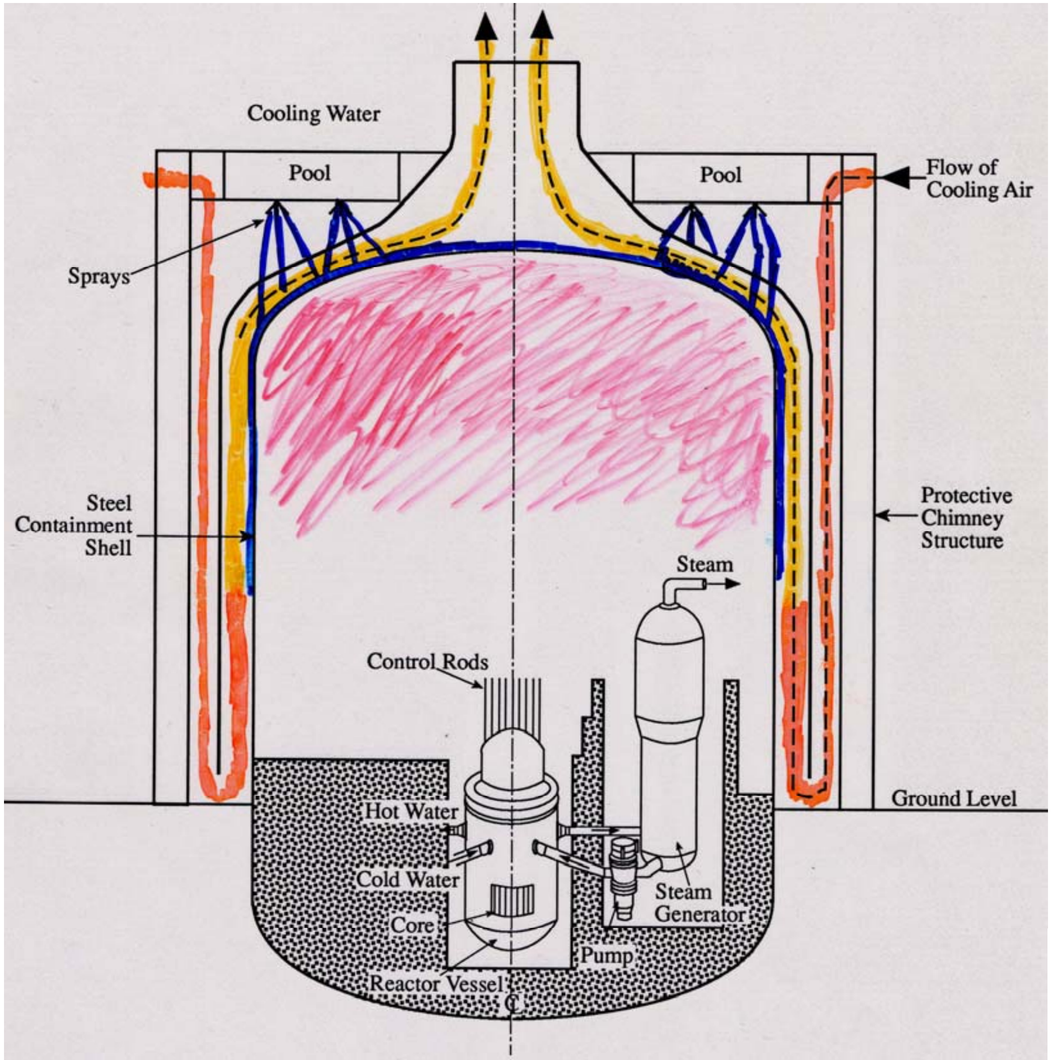


PWR – AP600


STAGE 3
STAGE 2
STAGE 1
SECOND
DEPRESS.
VALVE GROUP
FIRST
DEPRESS.
VALVE GROUP
IRWST
(1 of 1)
PRHR
HX
(1/1)
(1 of 2)
from
SUMP
PRESSURIZER
ACCUM.
(1 of 2)
N2
CORE
MAKEUP
TANK
(1 of 2)
HL
CL
REACTOR
VESSEL
FUEL
STAGE 4
DEPRESS.
CONT.

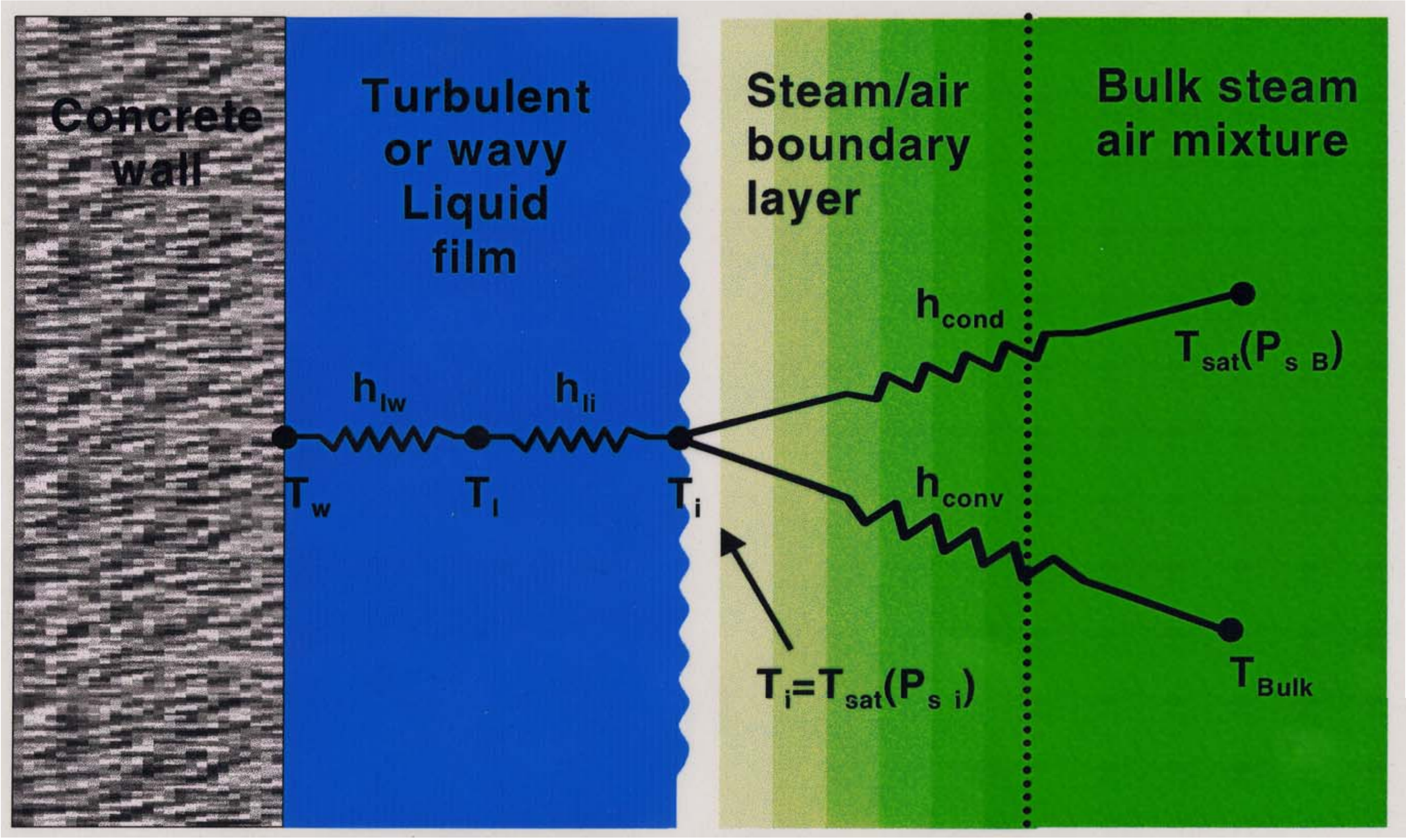
Concepts to Dump Heat to Ultimate Heat Sink

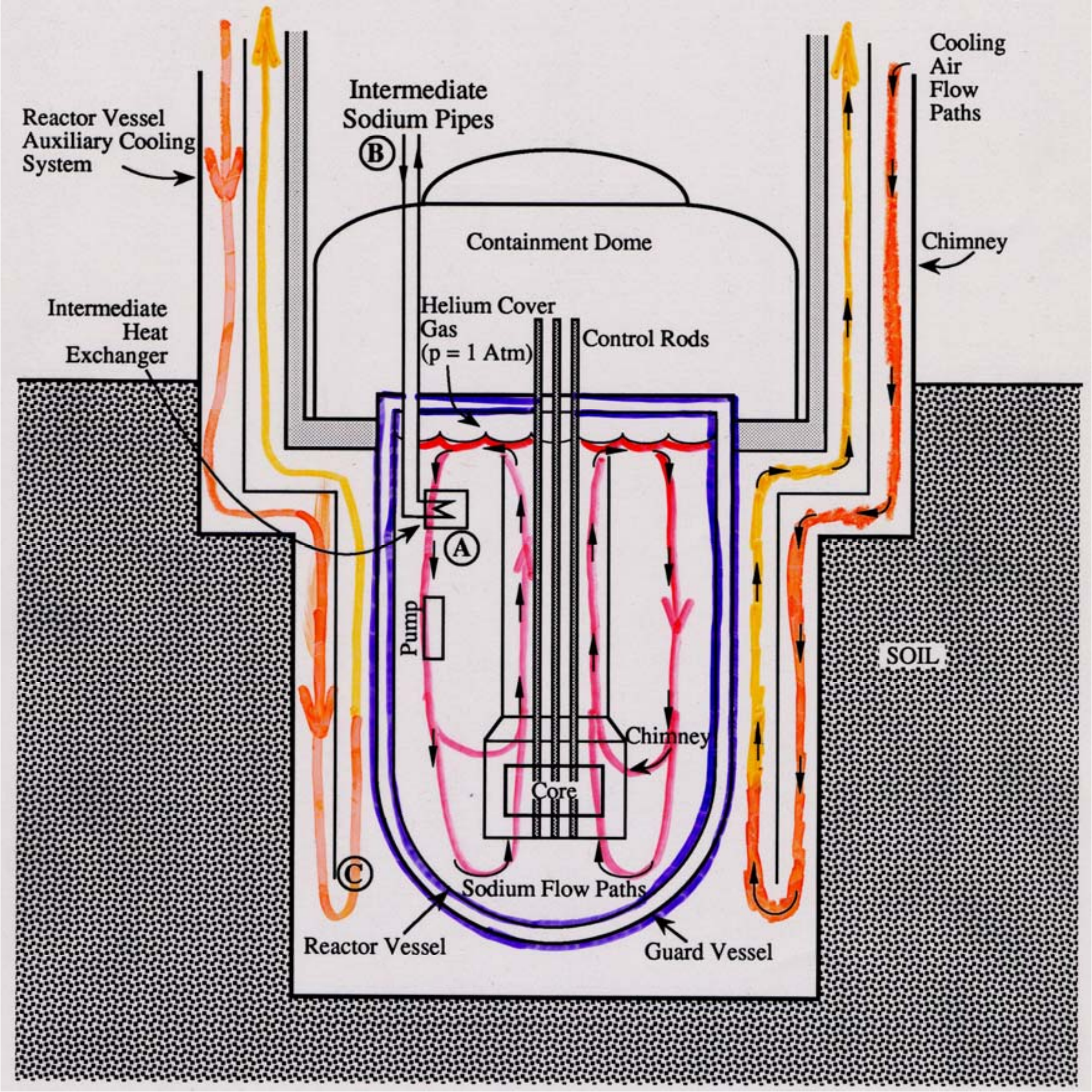




Schematic View of the AP-600 Reactor Concept, showing the containment building and associated cooling systems

Heat/Mass Transfer Model





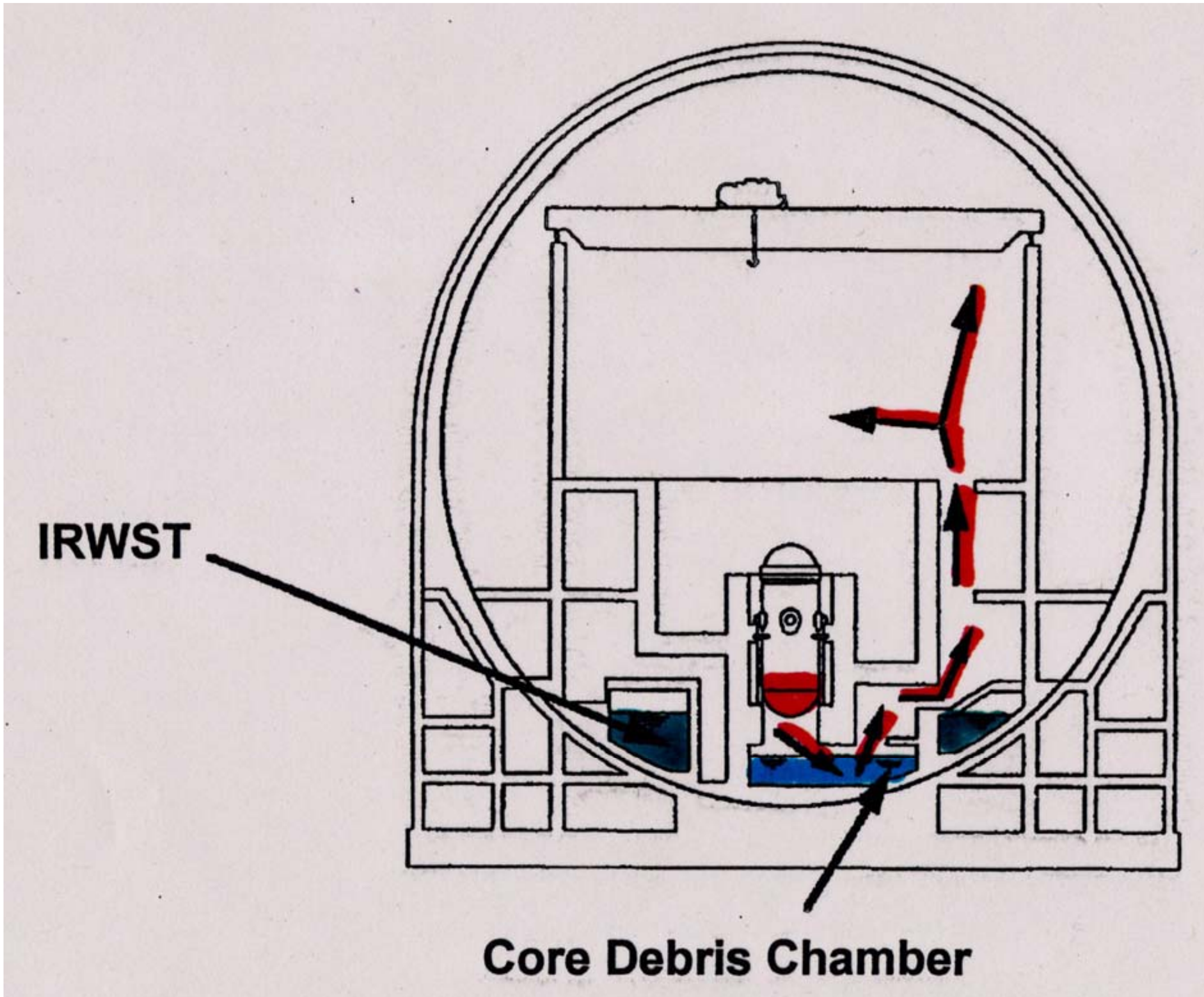
Courtesy of U.S. DOE.

Schematic View of the IFR/ALMR Reactor Concept, showing the reactor coolant and major safety systems

Severe Accident Issues Resolved

- Core debris coolability
- Hydrogen burning
- Direct containment heating
- Core concrete interaction
- Steam explosions

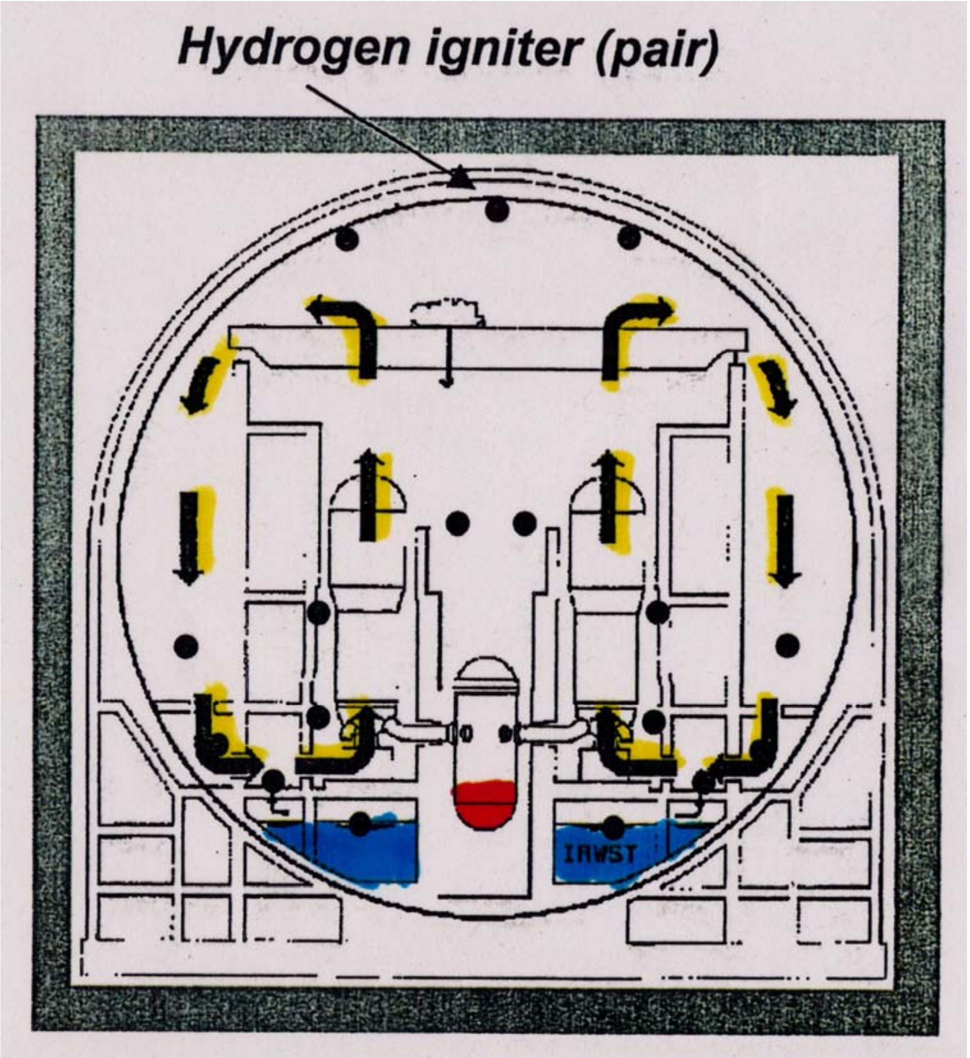
Core Debris Chamber and Cavity Exit Pathway on System 80+ Design



Courtesy of Regis Matzie. Used with permission.

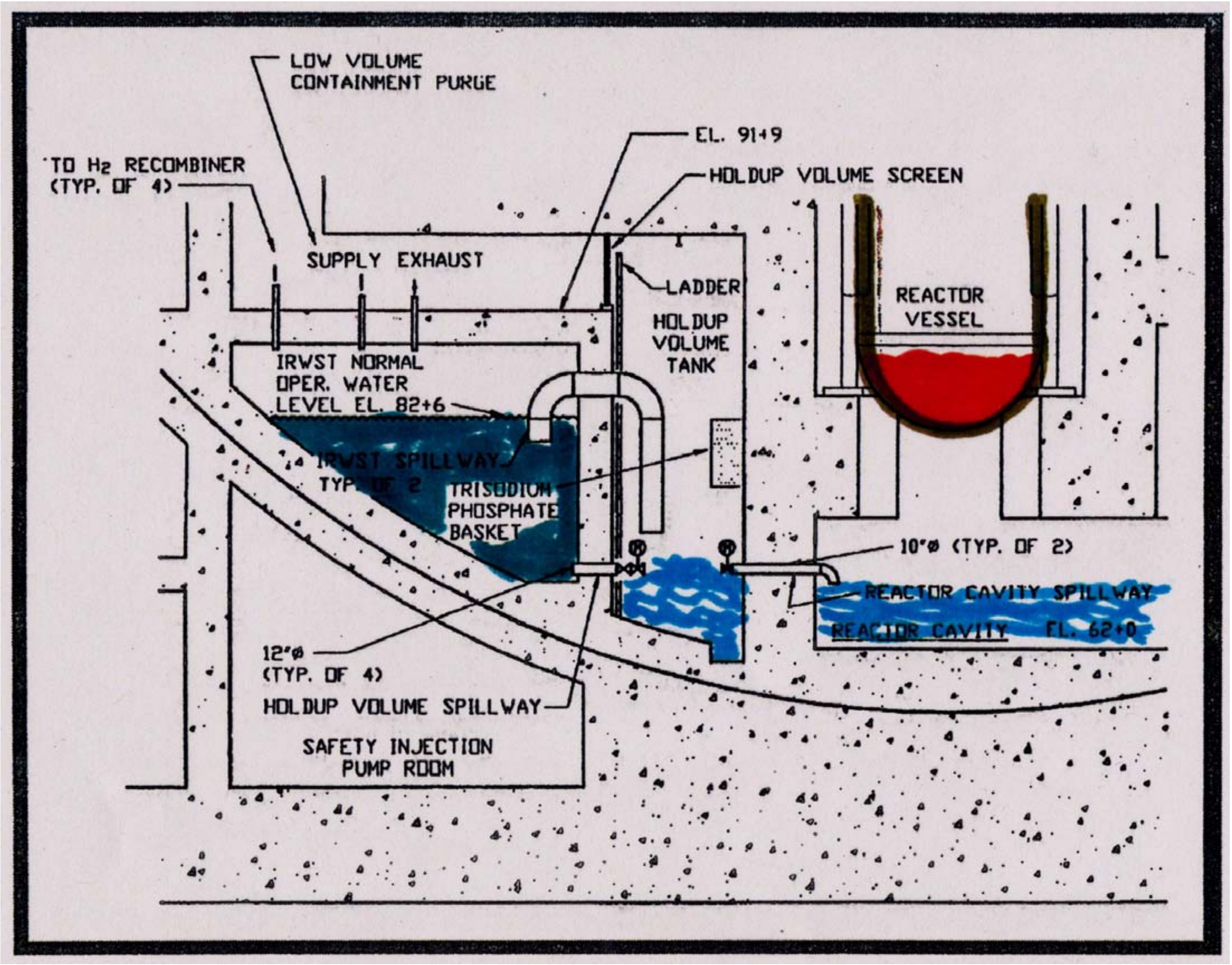
Containment Atmosphere Hydrogen Control in System 80+ Design

- 80 Igniters located in pathways of generated hydrogen
- Approximately half are battery-backed



Courtesy of Regis Matzie. Used with permission.

System 80+ Cavity Flooding System



Courtesy of Regis Matzie. Used with permission.

Paradigm – Altering Safety Assurance Differences*

PWR	GFR	LMR
Coolant is high pressure (15 MPa), H_2O liquid; Low boiling point, Good heat transfer	Coolant is high pressure (7-20 MPa), Gas: He, CO_2; Mediocre heat transfer	Coolant is low pressure (≤0.5 MPa), Liquid metal: Na, Pb; High boiling point, Excellent heat transfer
Some fraction of cooling inventory remains after LOCA	>98% of coolant escapes in a complete depressurization	Use of guard vessel retains adequate liquid inventory in reactor vessel
Large liquid reflood reservoir is available; Boiling and heat of vaporization facilitate cooling	Limited high pressure gas injection available; At low pressure only air available in large amount	Can design for passive decay heat removal by natural convection to ambient air or water
Post-LOCA goal is timely reduction of containment pressure to reduce leakage Reducing pressure after shutdown does not negatively impact coolability	Maintaining high pressure facilitates long term cooling, especially via natural convection Low pressure is always detrimental to heat transfer and transport; Cooling capability is proportional to pressure; Adequate natural convection only at several atmospheres	System is low pressure
Refueling under water at 1 atm can rely on an effective passive heat sink; Visual observation possible	Cooling during depressurized refueling is challenging; Refueling at high pressure creates more LOCA sequences; Visual observation possible	Refueling is at low pressure, but blind; Heat removal is assured
Benign reactor physics characteristics; Negative coolant void reactivity (in common with most thermal reactors)	Small delayed neutron fraction and Doppler reactivity; Positive coolant void reactivity (in common with all fast reactors); Fuel compaction and recriticality	Small delayed neutron fraction; Modest Doppler reactivity; Large local positive void reactivity; Fuel compaction and recriticality

*Driscoll, 12/05

Paper Reactors, Real Reactors

Characteristics of an Academic Plant

- It is simple.
- It is small.
- It is cheap.
- It is light.
- It can be built very quickly.
- It is very flexible in purpose.
- Very little development is required. It will use mostly off-the-shelf components.
- The reactor is in the study phase. It is not being built now.

Characteristics of a Practical Reactor Plant

- It is being built now.
- It is behind schedule.
- It is requiring an immense amount of development on apparently trivial items. Corrosion, in particular, is a problem.
- It is very expensive.
- It takes a long time to build because of the engineering development problems.
- It is large.
- It is heavy.
- It is complicated.

(H.G. Rickover, The Journal of Reactor Science & Engineering, June 1953)