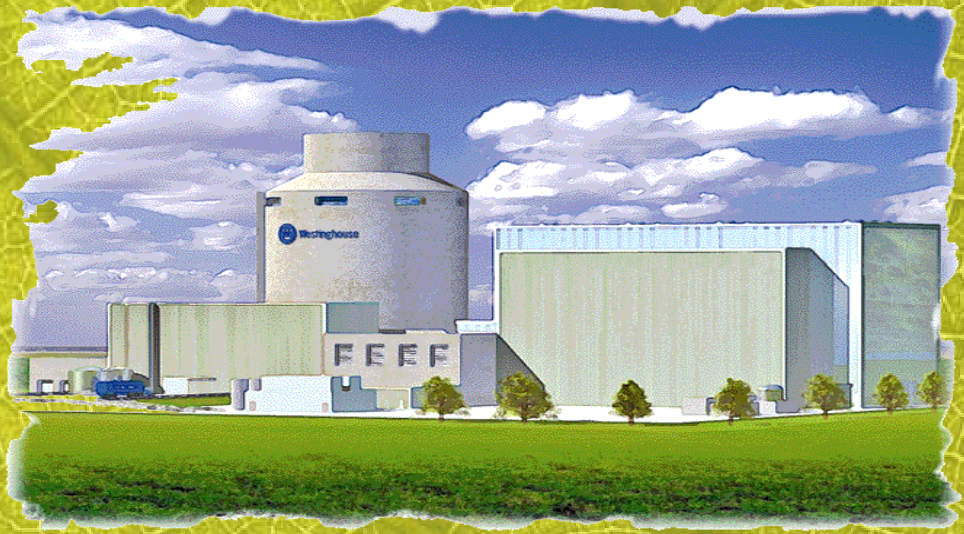
AP1000: The PWR Revisited



IAEA

International Conference on Opportunities and Challenges

for Water Cooled Reactors in the 21st Century

aolo Gaio

estinghouse Electric Company

ctober 27, 2009

Background

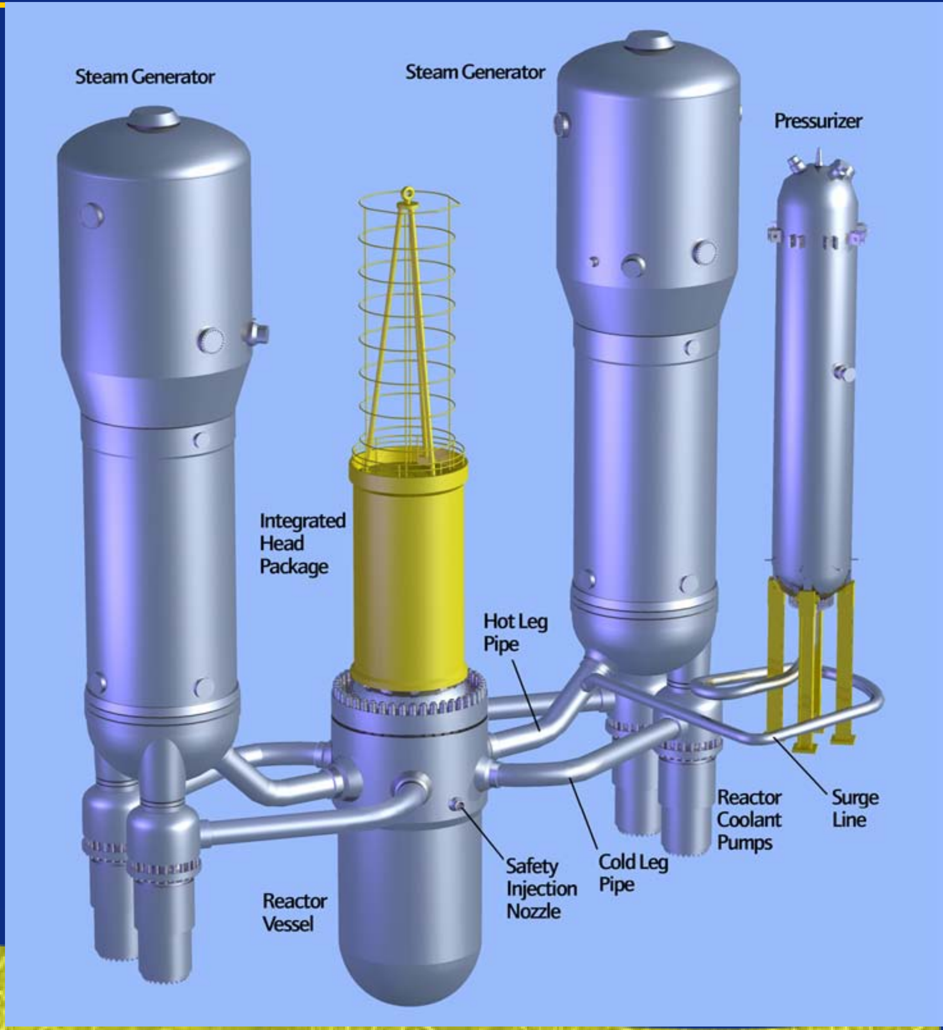
- Late ’80: USA Utilities under direction of EPRI and endorsed by NRC : *Advanced Light Water Reactor Utility Requirements Document (URD)* with policy and design requirements for next generation
- URD addresses **evolutionary** and **passive** LWR
- **Passive** has much higher expectations (ex. maintain safe shutdown for 72 hrs. after design base event w/o operator action vs. 30’ for evolutionary)
- **Passive** is also *simpler, smaller and much improved*
- In Europe similar document *European Utility Requirements (EUR)*

Westinghouse

AP 1000:
The Reactor Coolant System

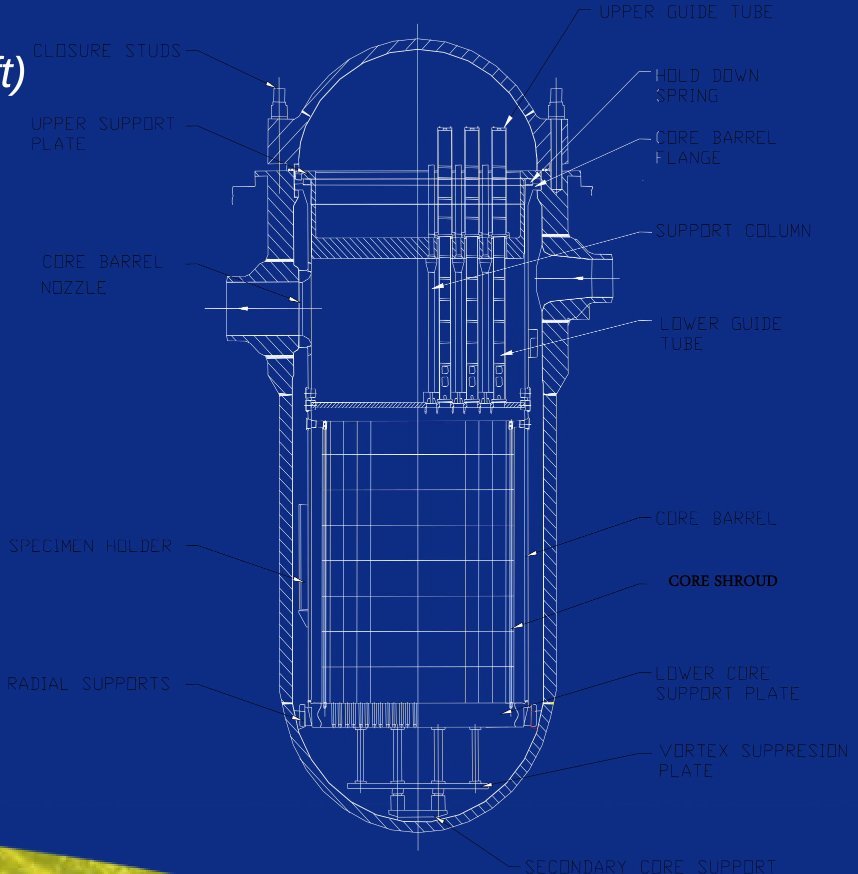
Familiar but Improved Reactor Coolant System

- Two loop plant: two cold and one hot leg
- Four Reactor coolant pumps mounted in steam generator lower head - No RCP shaft seals
- Larger pressurizer (2100 ft $^{-}$50% larger than operating plants) eliminate PORV
- Top-mounted, fixed in-core detectors
- Primary pipes forged in one piece reduces welds 50%, supports 80%
- Ring-forged reactor vessel (no longitudinal welds)
- All-welded core shroud (not bolted)
- Fuel, Internals, Reactor Vessel
  - Similar to Doel 4, Tihange 3, S. Texas
  - Improved materials - 60 yr life
- Steam Generators
  - Similar to large Westinghouse SGs in operation



AP1000 Reactor Vessel

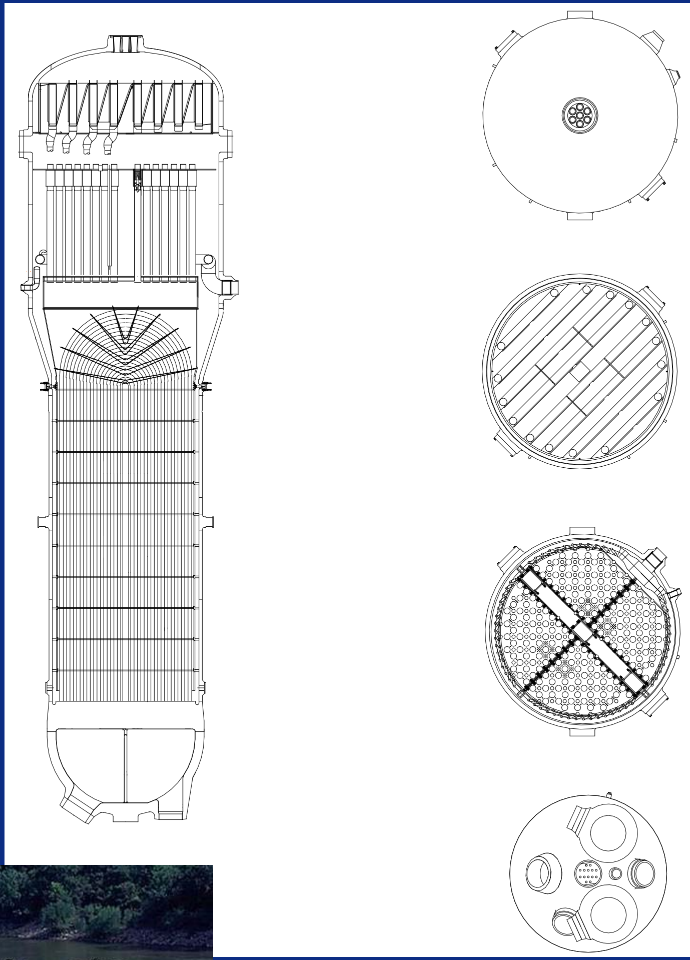
- Westinghouse 3-loop Reactor
  - 3.99m (159in) ID, *157 fuel assemblies*
  - *Longer vessel to accommodate 4.27m (14ft) fuel*
  - Ring forged construction
    - No welds in core region
  - Improved materials permit
    60- yr design life
  - *W-CE-type core shroud*
    - *Replaces radial reflector*
    - *All-welded design*
  - Top-mounted in-core I&C
    - Fixed position, online readout
    - No penetrations in bottom vessel



Westinghouse

AP1000 Steam Generator

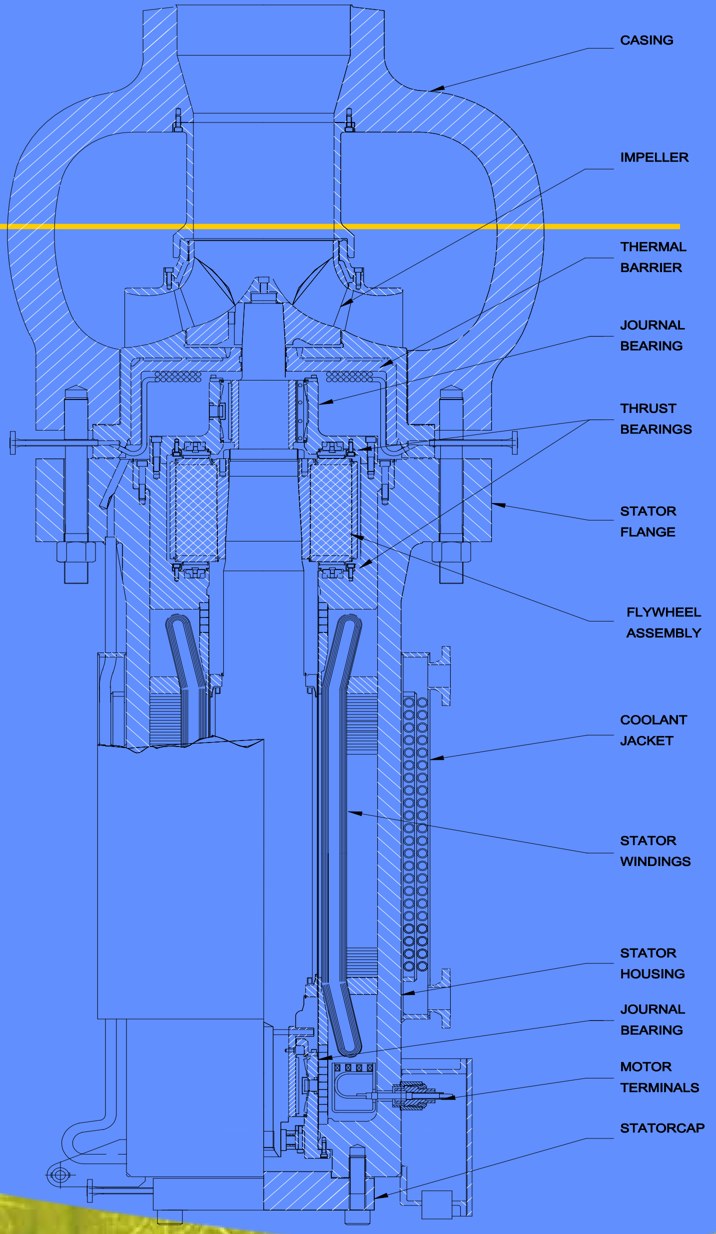
- Based on proven Westinghouse designs
  - AP1000 design based on ANO RSG
  - Design Features
    - Inconel 690 TT tubes
    - Stainless steel support plates
    - Improved access
    - Excellent operating experience
  - Over 1,200 SG years of operation
  - Less than 0.1% total tubes plugged



Westinghouse

AP1000 High Efficiency Reactor Coolant Pump

- **Canned Motor Pump**
  - **- No shaft seal leakage or support system**
  - **- No seal (LOCA benefit)**
  - **- No oil cooling system**
  - **- Reduced maintenance**
  - **- Excellent operating experience**
  - **- High inertia bearing**
  - **- Pump design will be verified through extensive testing**



Westinghouse

Comparison of Selected Parameters

PARAMETER	Doel 4 / Tihange 3	AP1000
Net Electric Output, MWe(2.5"HgA)	985	1117
Reactor Power, MWt	2988	3400
Hot Leg Temperature, ^{o}F	626	610
Number of Fuel Assemblies	157	157
Type of Fuel Assembly	17x17	17x17
Active Fuel Length, ft	14	14
Linear Heat Rating, kW/ft	5.02	5.71
R/V I.D., inches	157	157
Vessel Thermal Design Flow, gpm	295,500	299,880
Steam Generator Surface Area, ft^2	68,000	125,000
Reactor Coolant Pump Flow, gpm	103,400	78,750
Pressurizer Volume, ft^3	1400	2100

Westinghouse

AP 1000:
The Passive Safety System

Passive Safety – What's it all about?

- Passive Safety Systems utilizes naturally occurring physical phenomena such as natural circulation of air, water and steam
- ***Gravity*** and gas pressure drive the flow of cooling water
- ***Natural heat transfer*** occurs through conduction, convection and evaporation

- There are no safety related pumps and motor-operated valves
- There is no safety related ventilation system

- Reactor safety functions are achieved without using any safety related ***AC power*** rely on "stored" energy
- A few battery powered valves - 20 in total, most "fail safe" - align the passive safety systems upon actuation signals ("one time" alignment)

Westinghouse

Passive Safety – What's it all about? (Cont.)

- Typical PWR Safety Systems and Safety-Related Support System exist as simplified, non-safety systems housed in non-safety related structures ***(defense in depth):***

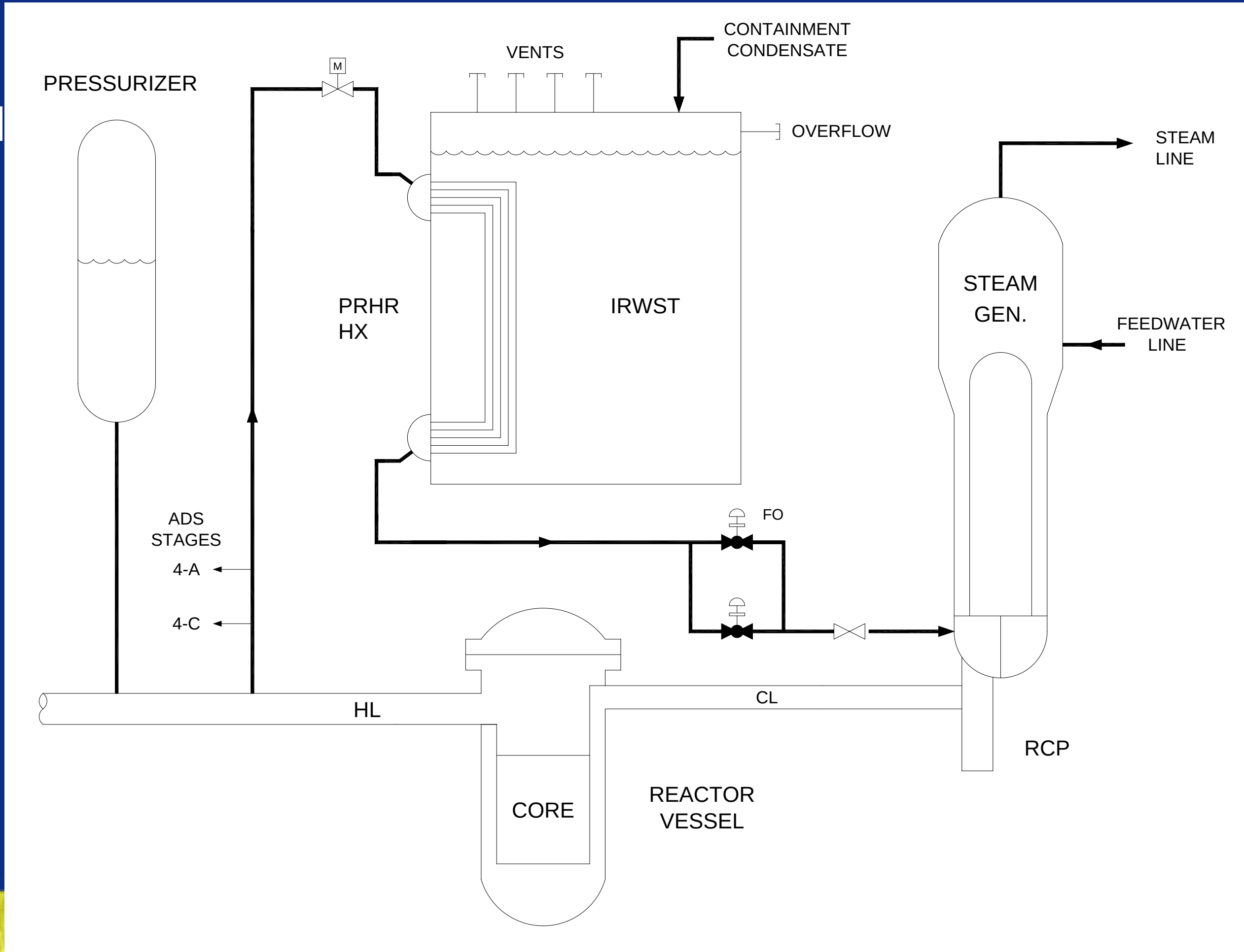
- Diesels	- Instrument Air
- Chilled Water	- Hot Water (heating)
- Component Cooling	- Essential Service Water
- Spent Fuel Cooling	- Residual Heat Removal
- Diesel Support Systems (Fuel Oil, HVAC)	- Startup Feedwater (replaces Auxiliary Feedwater)

- The Non-Safety, Active Systems are credited in the PRA, but are *not* required for reactor safety and are *not* required to achieve NRC required CDF of $1x10^{-4}$
- Severe Accident Scenarios are mitigated by In-Vessel Retention of the melted fuel. (The core is retained in a cooled reactor vessel)

Westinghouse

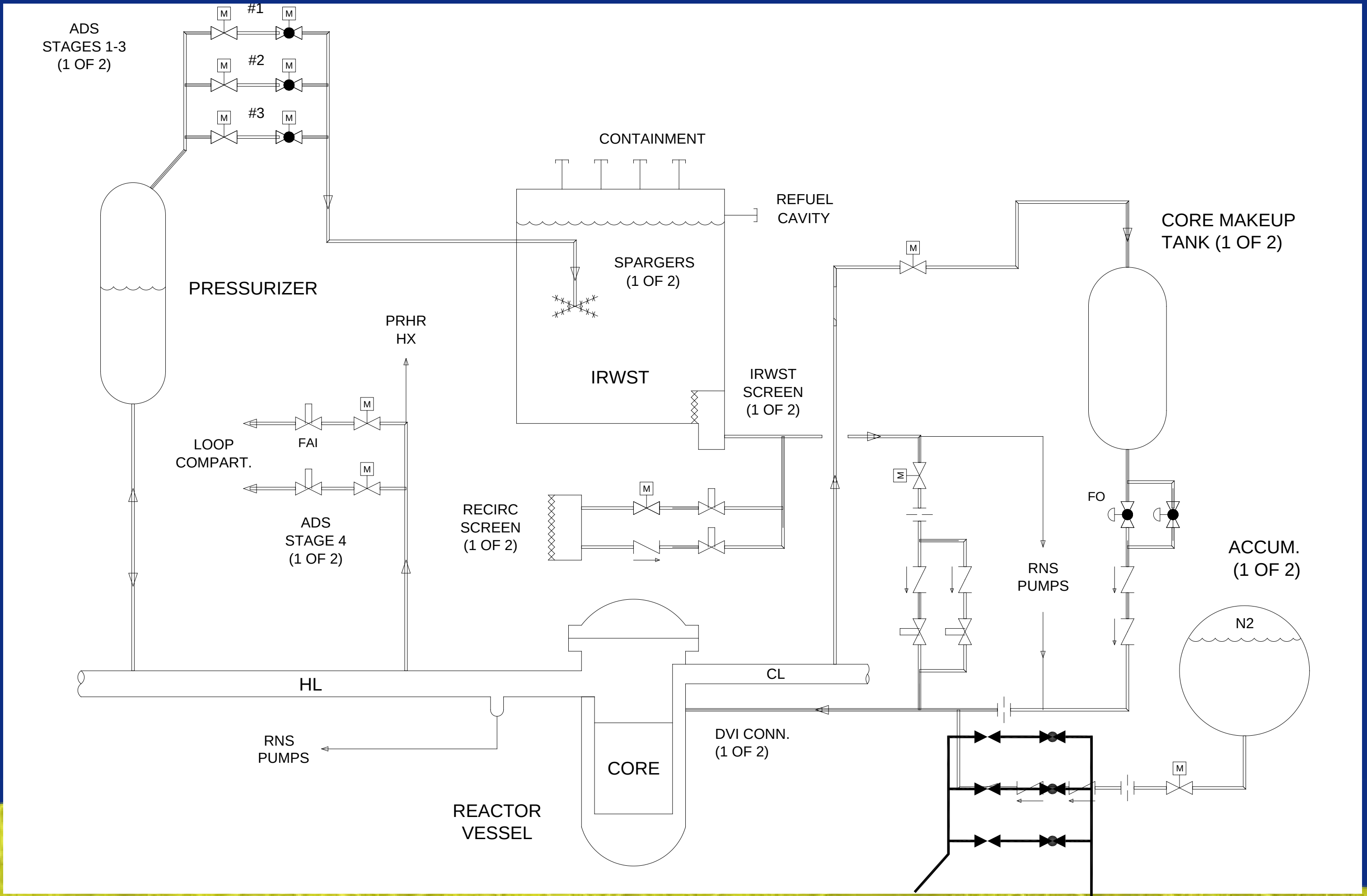
Passive Decay Heat Removal

- PRHR (Passive Residual Heat Removal) normally isolated by two AOVs, fail open
  – Opening 1 AOV actuates RCS cooling via natural circulation
  – AOVs actuated by PMS and by DAS
- IRWST absorbs heat
  – Takes ~ 2 hours to heat up to saturated
  – Steaming is condensed by PCS and returned to IRWST by gutter



Westinghouse

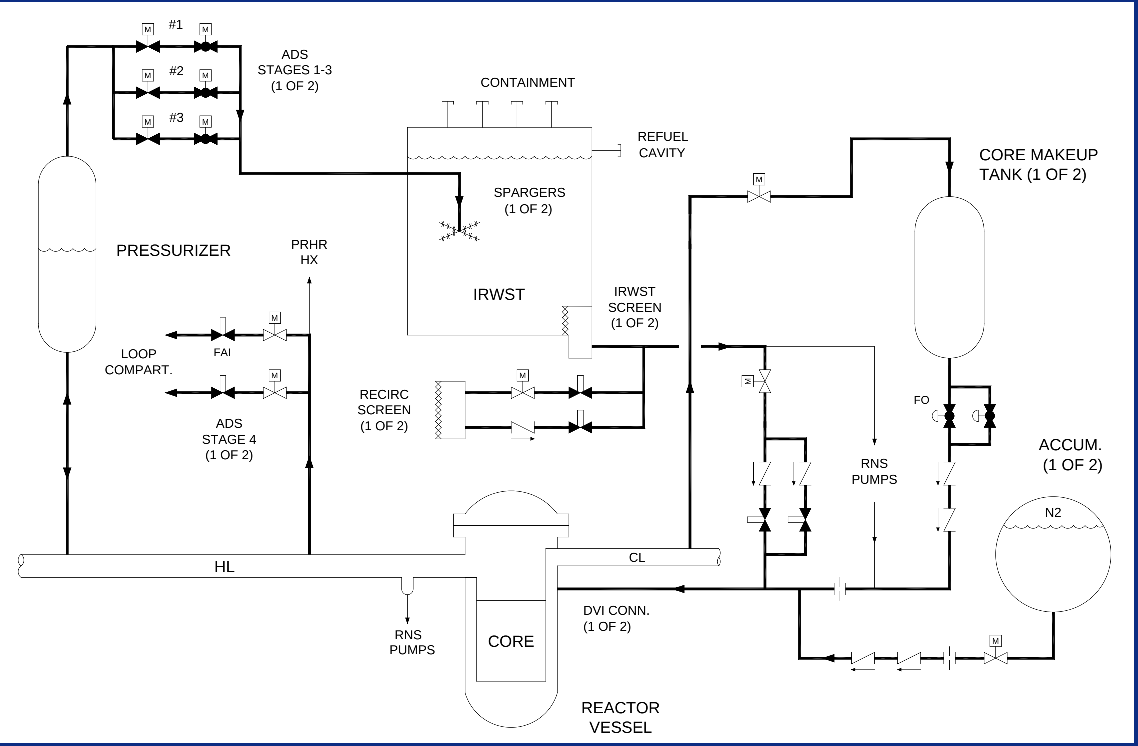
Passive Safety Injection



Westinghouse

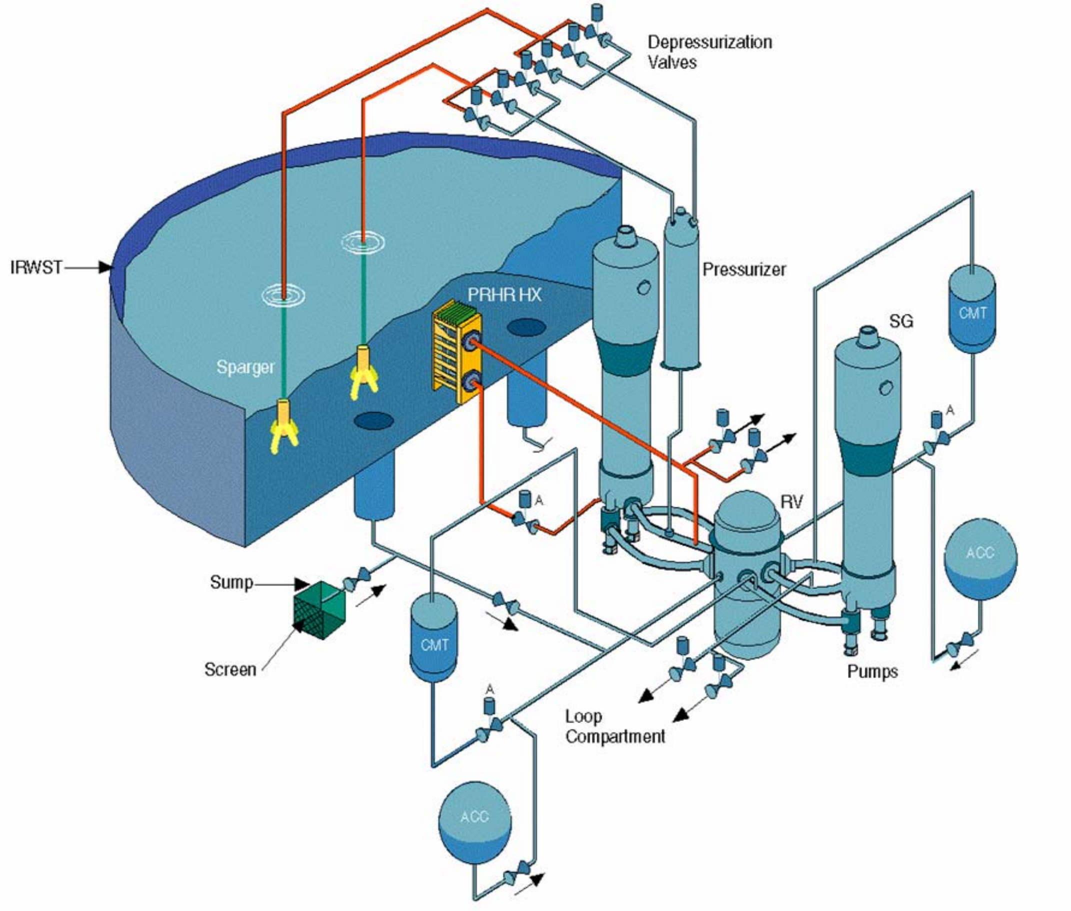
Passive Safety Injection

- Uses one time valve alignment
  - Accumulator uses check valves
  - CMT uses fail open AOV
  - ADS uses MOV for 1/2/3 and Squibs for 4
  - IRWST uses Squibs and check valves

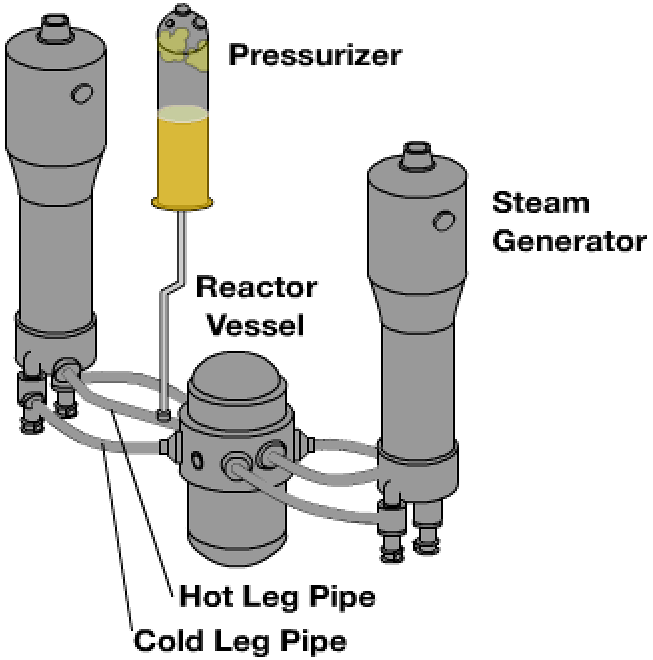


Simplicity in Design and Safety

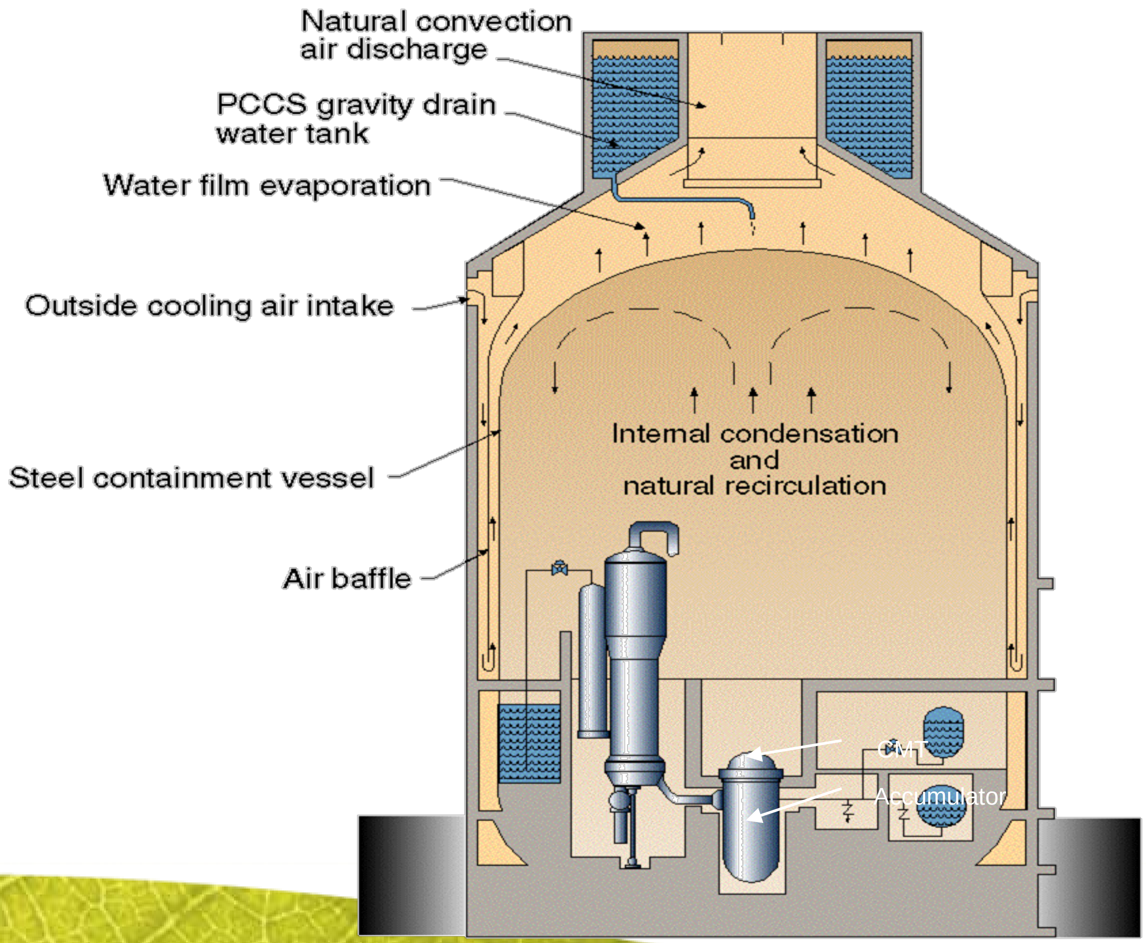
- No operator action for 72 hours
- AP1000 safety doe not rely on AC power
  - Passive decay
    heat removal
  - Passive safety injection
  - Passive containment cooling
- Uses passive safety systems
  - Proven by extensive testing and analysis
  - Extensively reviewed by USNRC
  - No safety pumps
  - No ac power required
  - One time valve alignment - Most are fail safe
- Provides improved margins
  - Transient DNBR margin > 15%
  - No core uncovery for SBLOCA
  - Breaks up and including a Direct Vessel Injection (DVI) line (8”) break
  - No operator actions required for SG Tube Rupture



Passive Core Cooling System Operation During a Small-Break LOCA

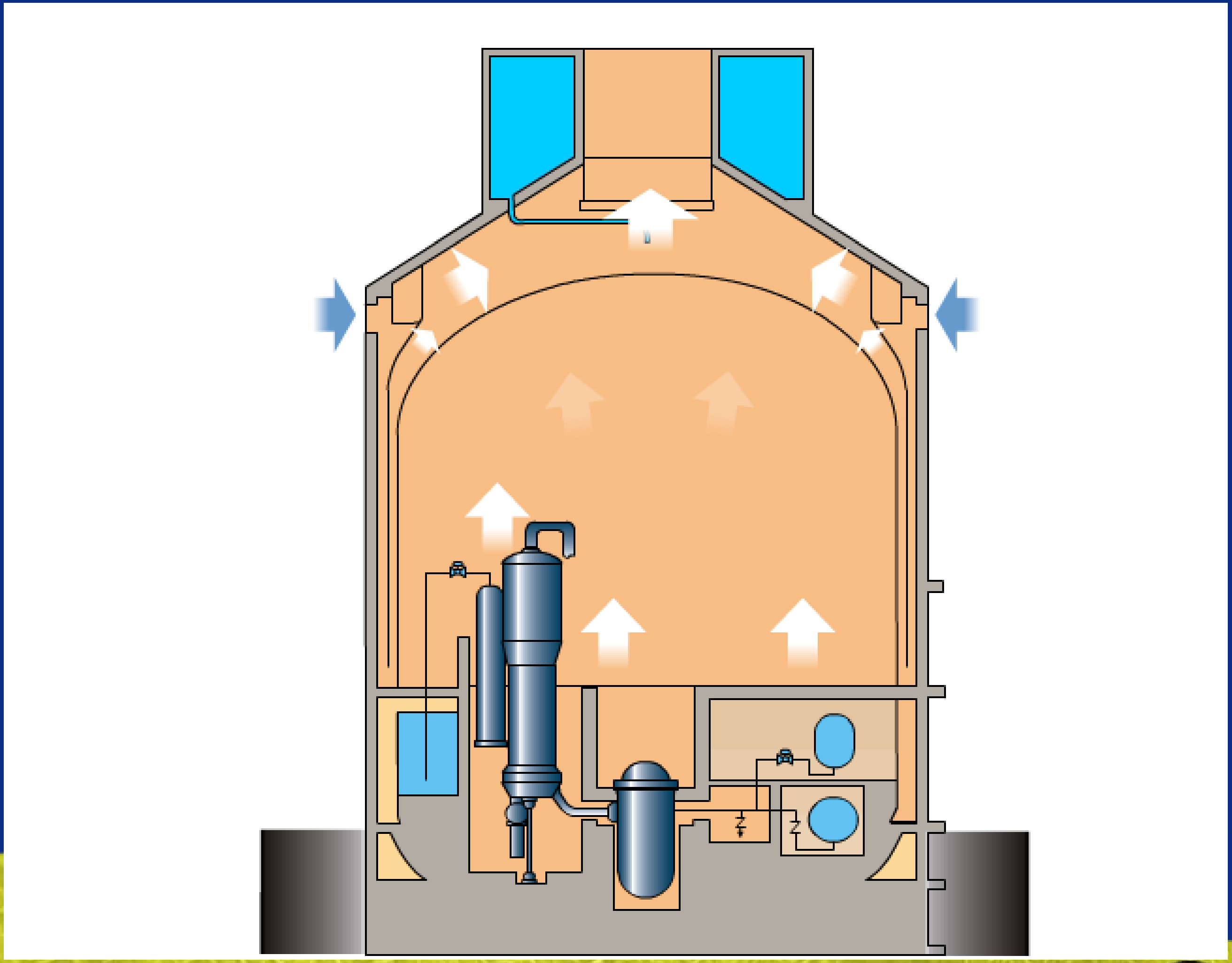


Passive Containment Cooling System

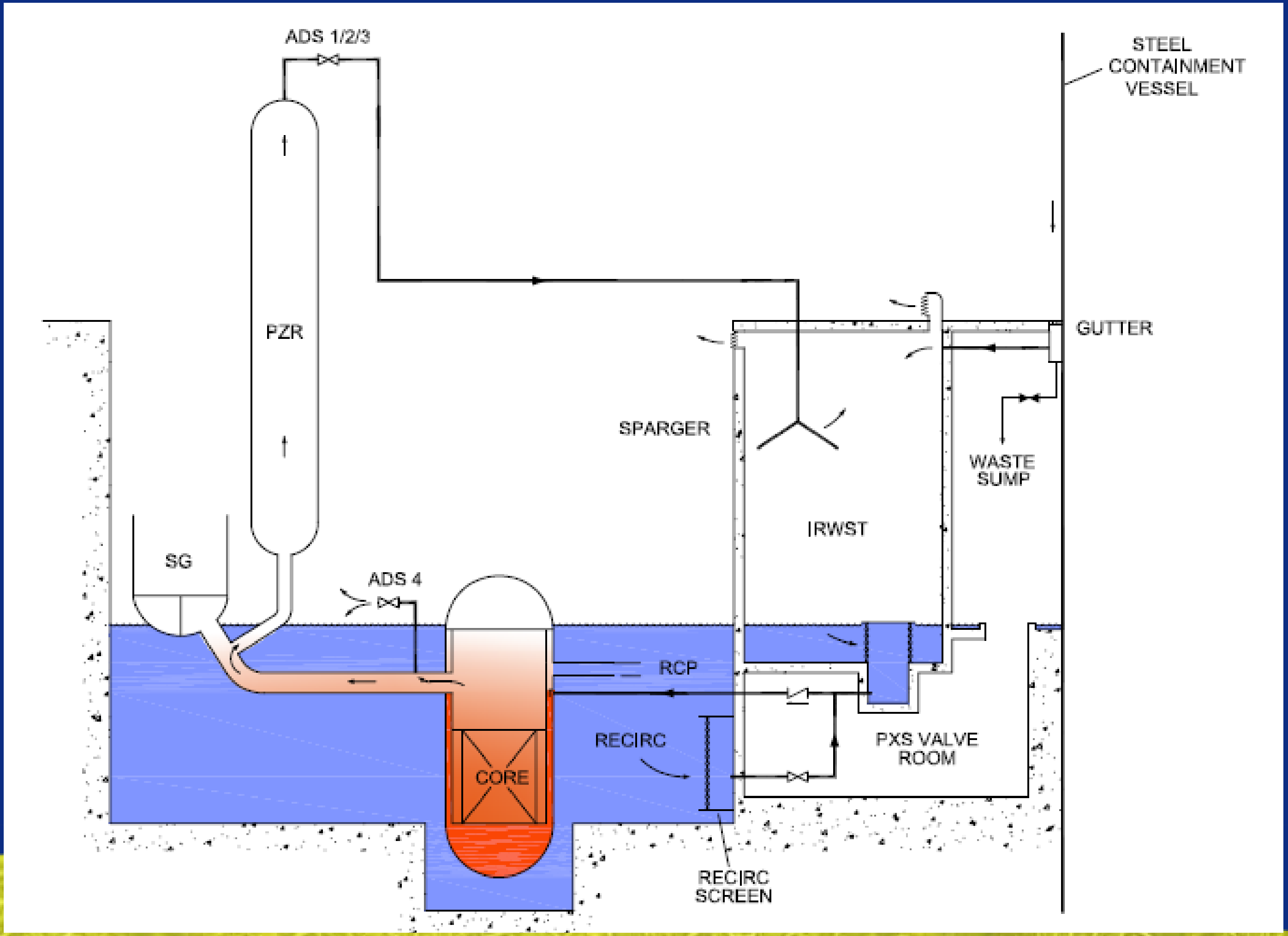


AP1000 Ultimate Heat Sink is the Atmosphere

Passive Containment Cooling Operation During a LOCA

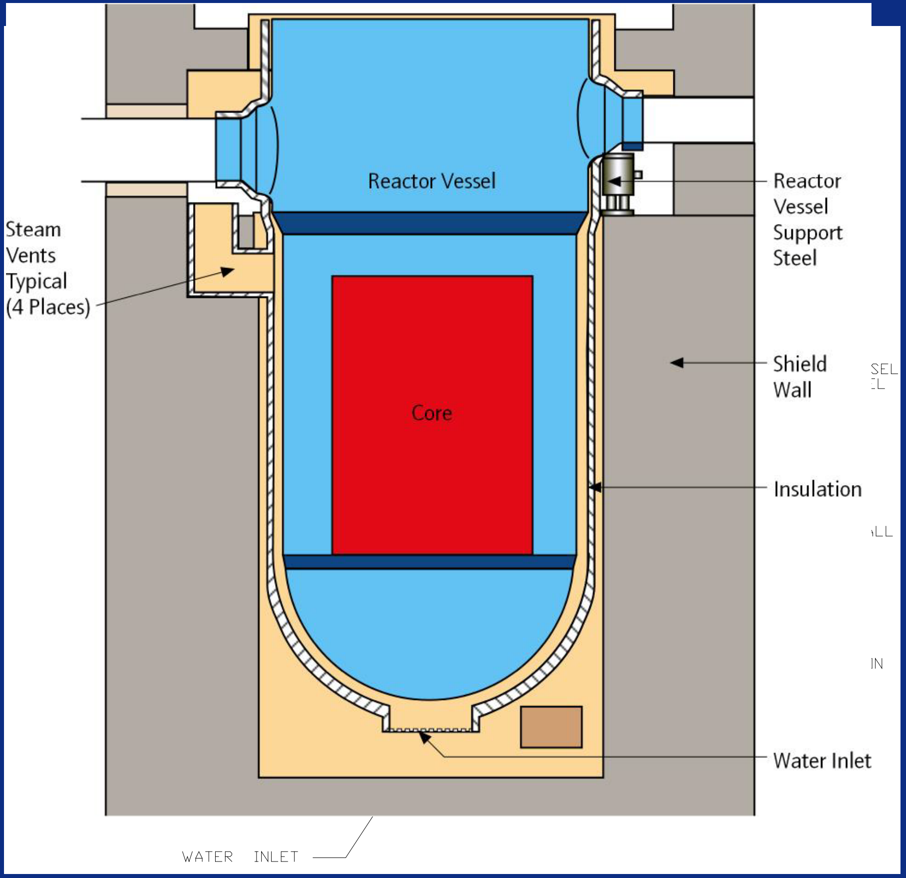


LOCA Long-Term Cooling

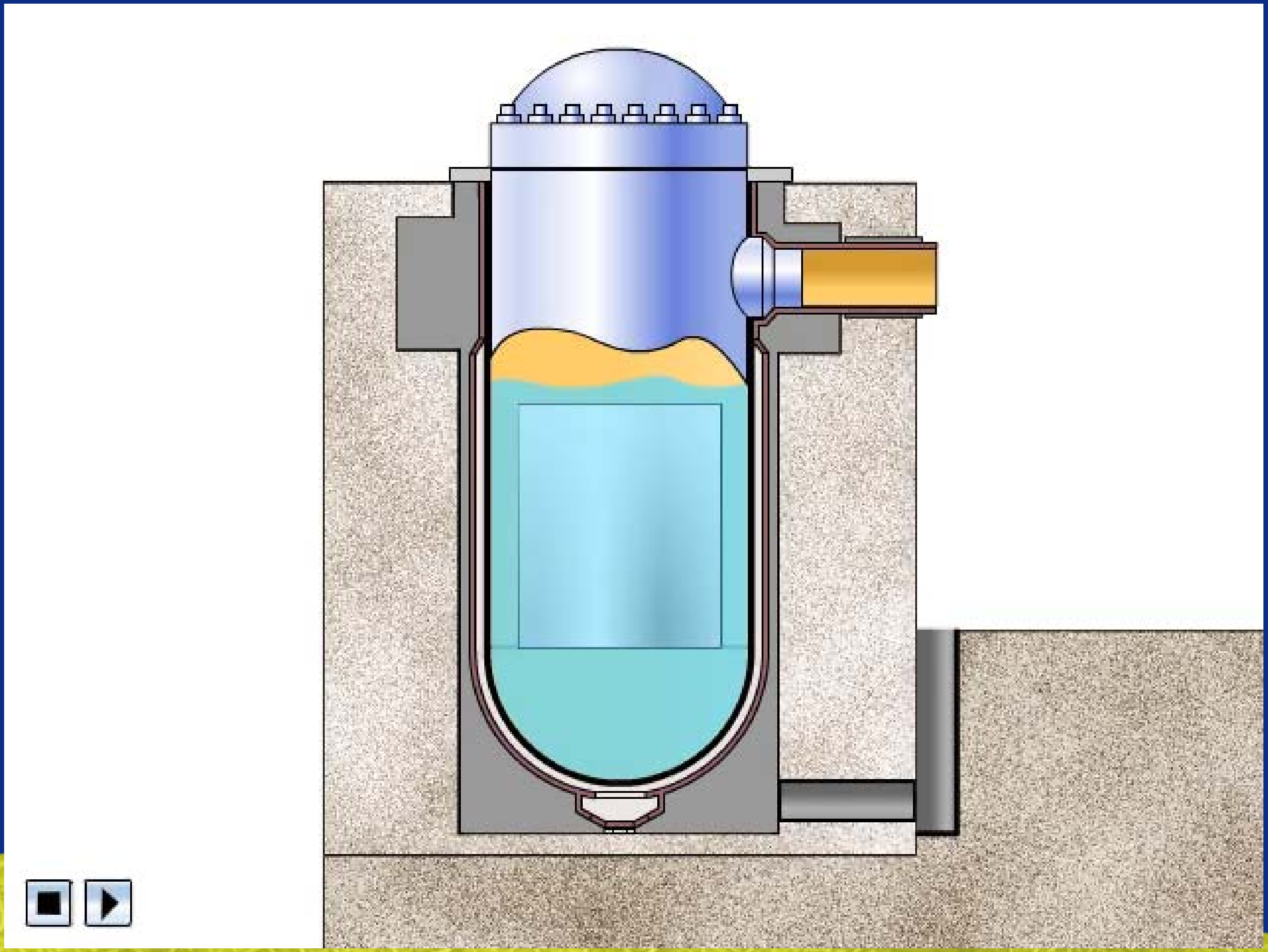


Simple Severe Accident In-Vessel Retention

- AP1000 designed to retain core debris <u>within the reactor vessel</u>
- Provides Reliable Means of Cooling Damaged Core
  - Tests and analyses reviewed by U.S. NRC
- In PRA Core Damage Sequences
  - Cooling flow driven by natural circulation
  - Water source: In containment refueling water storage tank
  - Cooling water flow path in vessel/ insulation annulus
  - Core heat transferred through RV wall
  - Water in containment removes heat from RV
  - ADS valves keep RCS pres low
  - Passive containment cooling transfers heat out of containment
  - Core debris retained inside reactor vessel
- Large release frequency: 5.9 x 10-8 per reactor year; URD requires < 10-6



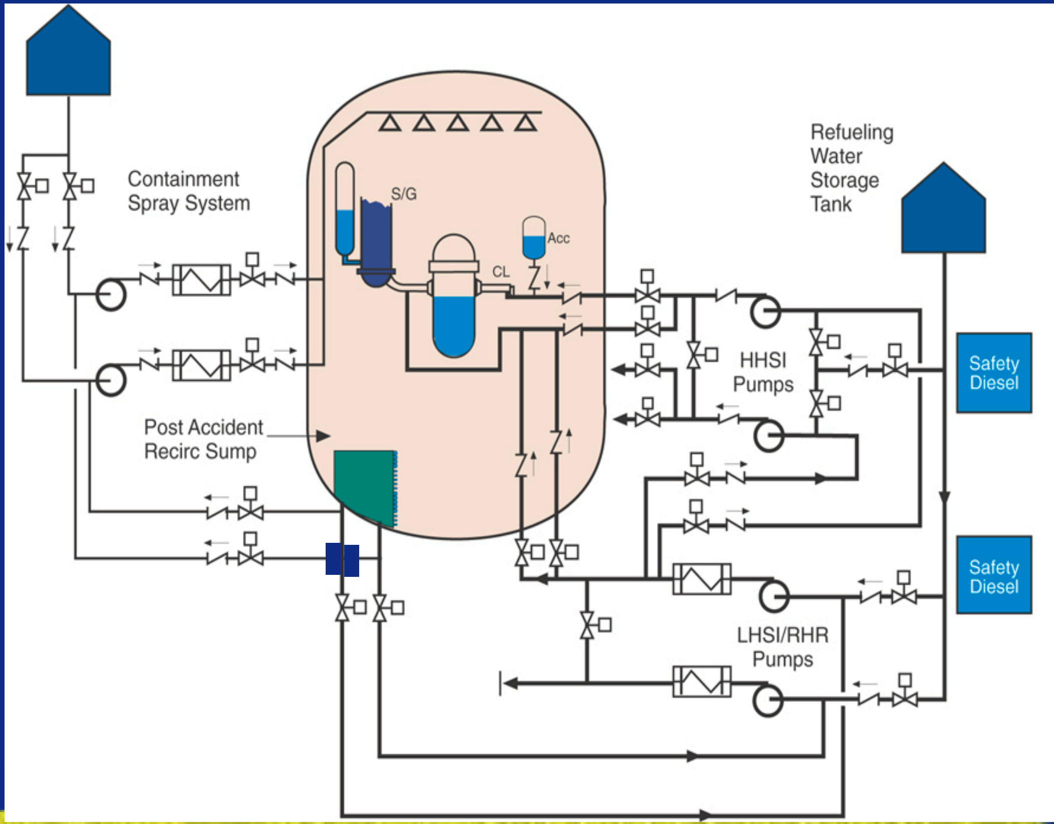
In-vessel Retention for Severe Accident Management



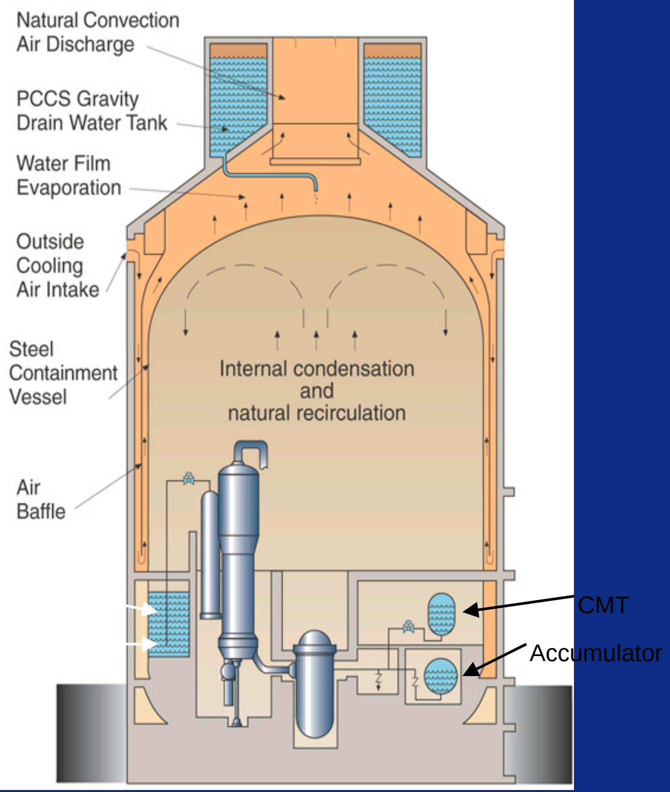
Westinghouse

Simplification of Safety Systems Dramatically Reduces Building Volumes

Standard PWR



AP1000



All Advanced Reactors Can Achieve Low Core Damage Frequency

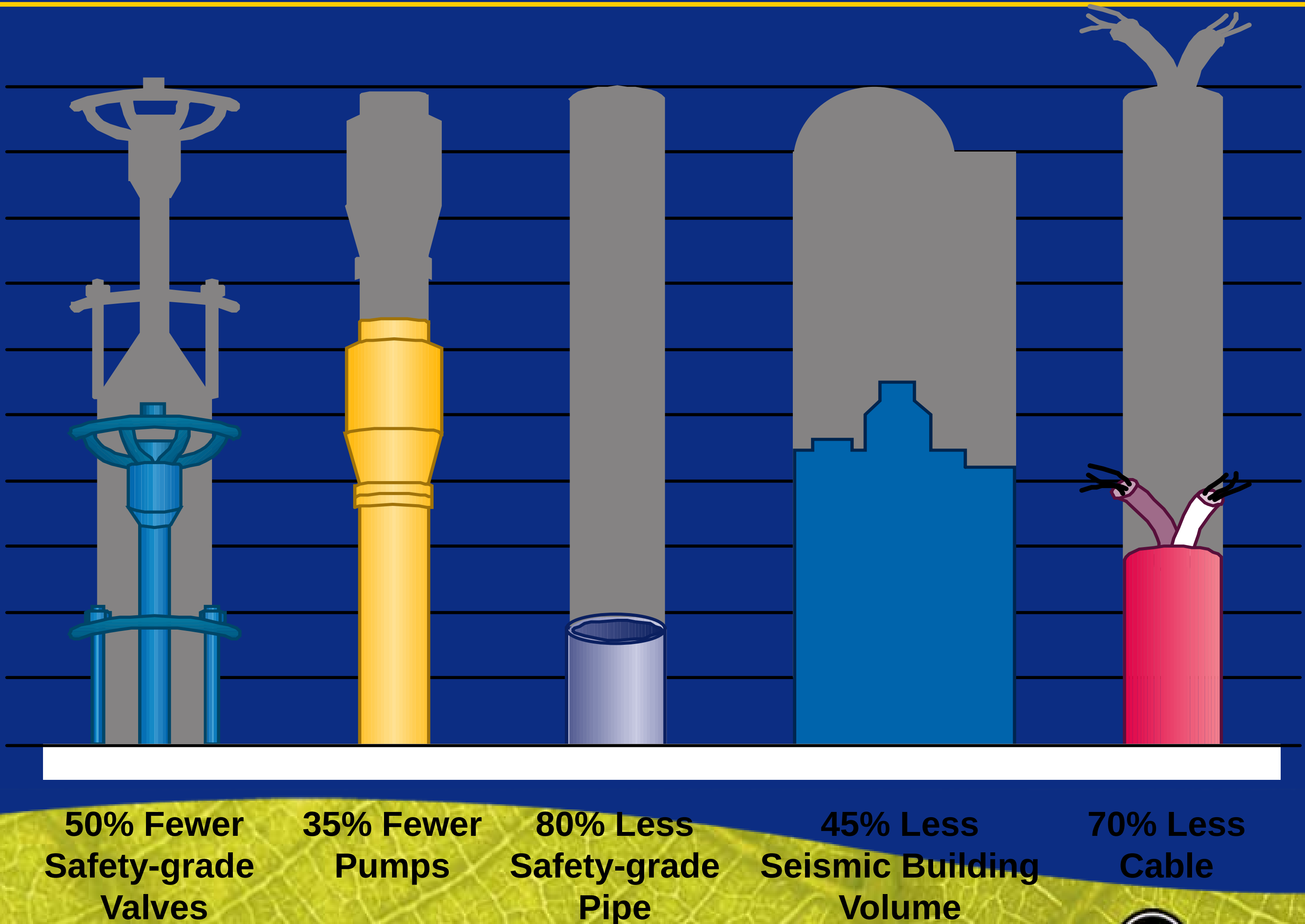
- Evolutionary plants achieve goals by **<u>adding</u>** redundant safety features
  - 4 Train Safety Injection
  - 4 Train Decay Heat Removal
  - 4 Train Containment Cooling
  - 4 Train Residual Heat Removal
  - 4 Train Diesel Generators

INCREASED CAPITAL AND O&M COST

- Passive Plants achieve goals by **<u>reducing</u>** active safety features
  - No safety related pumps
  - No safety related fans
  - No safety diesels/no safety AC power
  - Small number of valves actuate passive systems
  - Natural forces provide plant safety

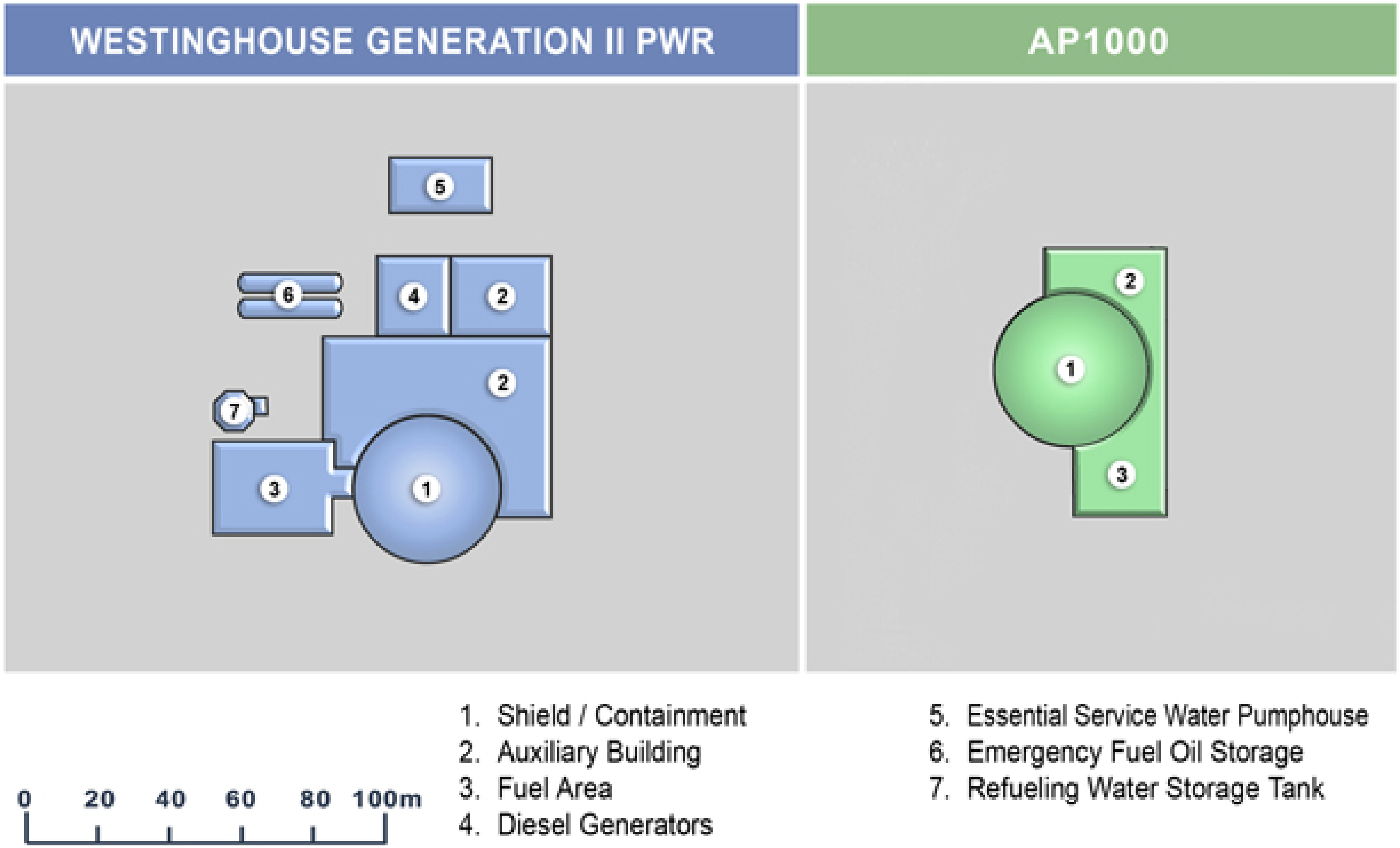
REDUCED CAPITAL AND O&M COST

AP1000 Passive Safety System Design Improves Economics and Construction Schedule



Westinghouse

Comparison of Seismic Category I Buildings



1. Shield / Containment
2. Auxiliary Building
3. Fuel Area
4. Diesel Generators
5. Essential Service Water Pumphouse
6. Emergency Fuel Oil Storage
7. Refueling Water Storage Tank

Westinghouse

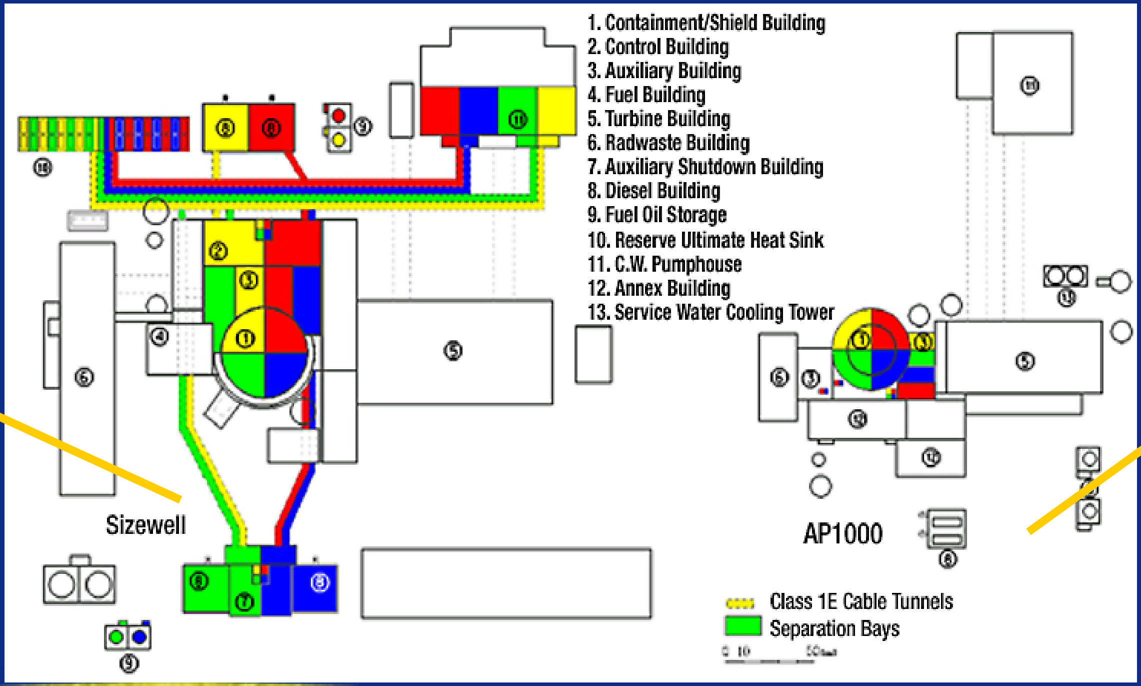
AP1000 Construction Simplification

Think: 1) more power/m^3 of concrete, 2) less to decommission

	Concrete, m^3	Rebar, metric tons	Power, MWe
Sizewell B:	520,000	65,000	1188
AP1000:	<100,000	<12,000	1117

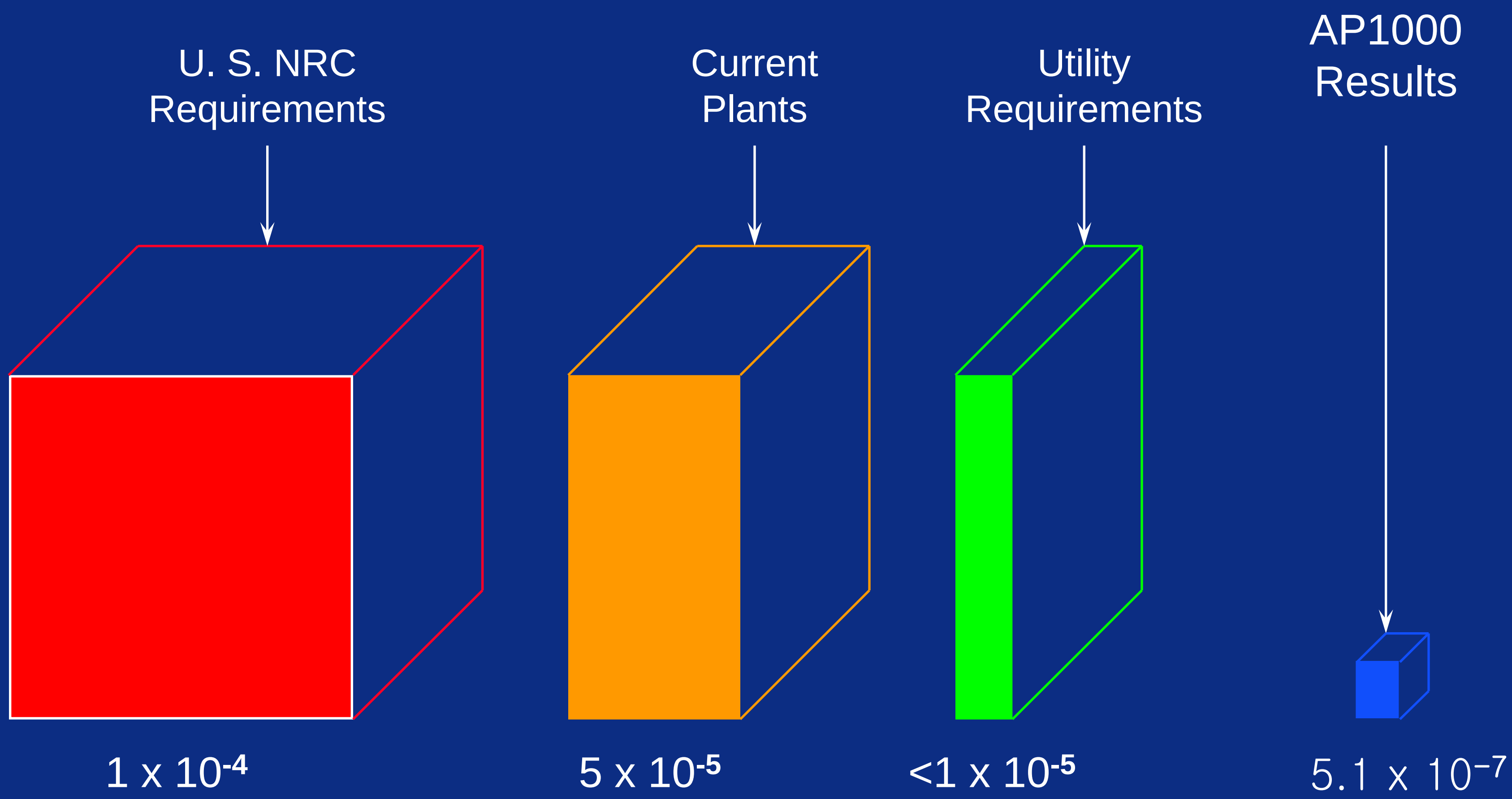
Sizewell B

AP1000



Westinghouse

AP1000 Provides Safety and Investment Protection



Core Damage Frequency per Year (All Events)

AP 1000:
The Most Tested Reactor

AP 1000 Mature design

- AP 1000 is the **most tested reactor** (USA, Japan, Italy)
- Licensing

  - NRC *(total staff4,000 people)* performed **independent and confirmatory plant tests** (ROSA Japan, Oregon State University)

  - NRC spent 110 man-year effort over 6 years (W spent 1,300 man-years…)

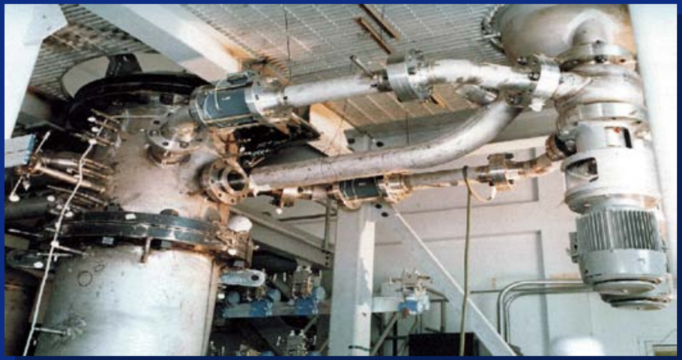
  - NRC asked 7,400 written questions

  - Finally NRC issued Design Certification in Dec. ‘99
- Meets UDR (US utility requirements)
- Meets EUR (European utility requirements)

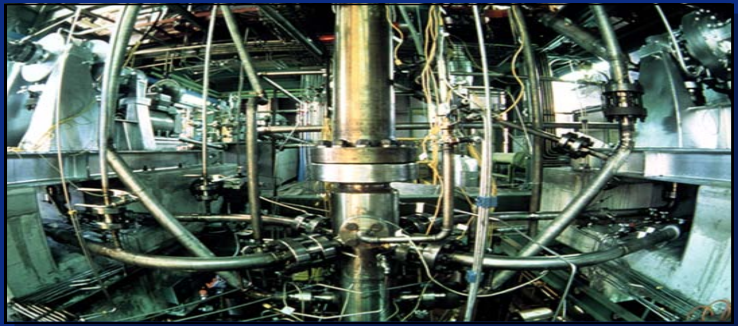
Westinghouse

Thorough Testing of AP1000 Passive Systems

- Definitely the Most Tested Reactor -



Oregon State ¼ Scale, Long Tern Integral Systems Test

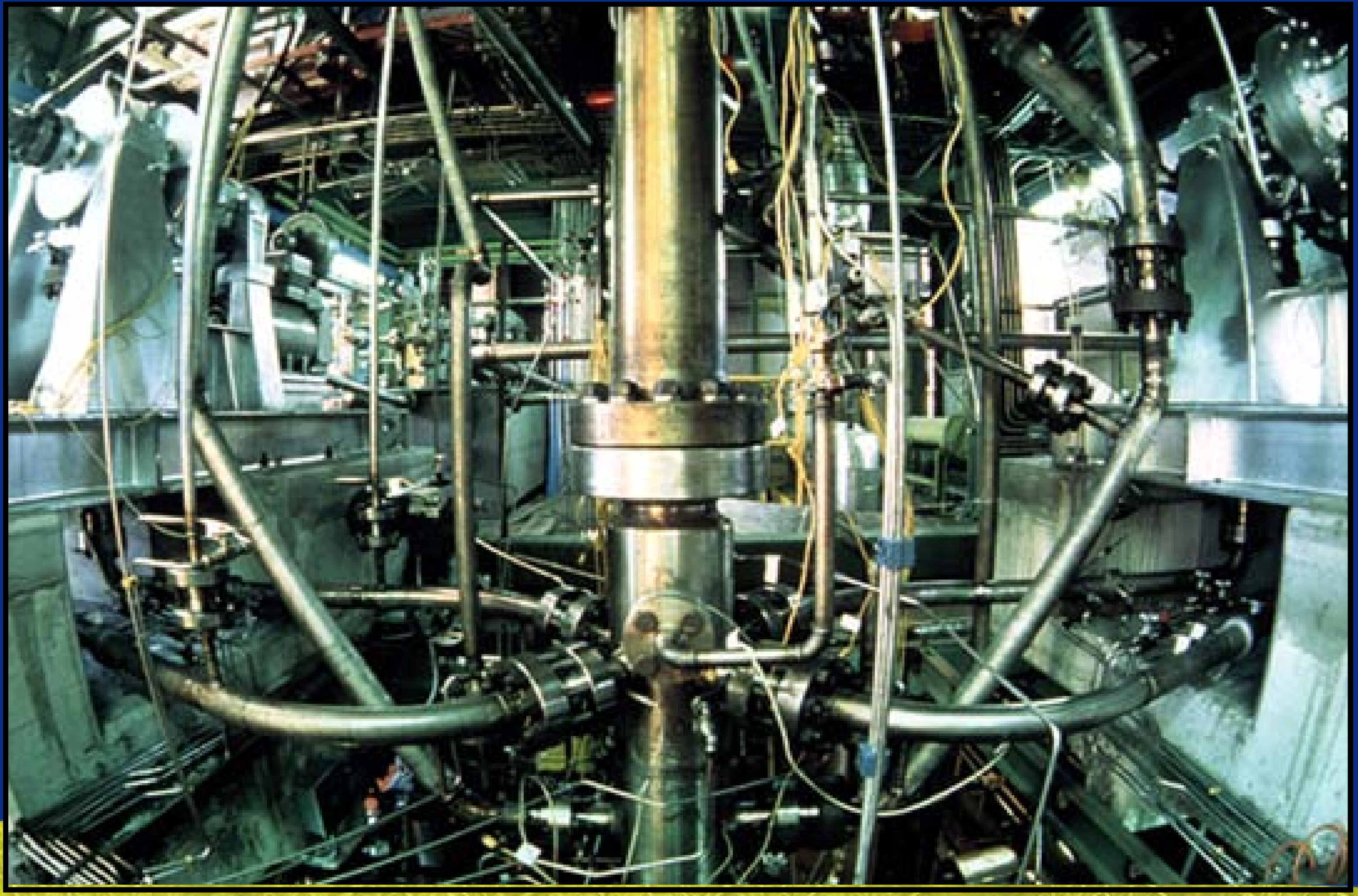


Full Height, Full Pressure, Integral Systems Test (SPES)

Large-Scale Containment Heat Transfer PCS Test

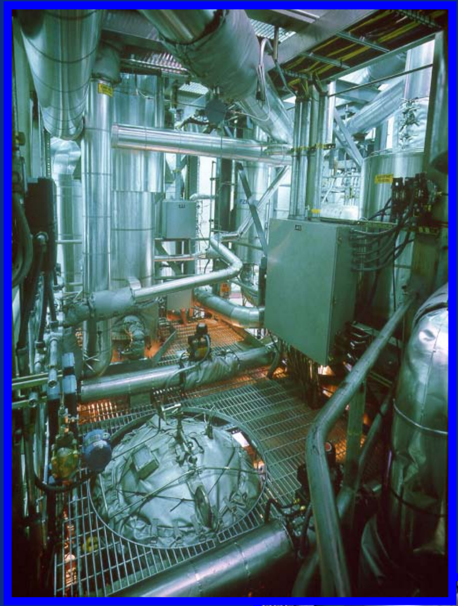
Westinghouse

Full Height, Full Pressure, Integral Systems Test (SPES-2 - Italy)

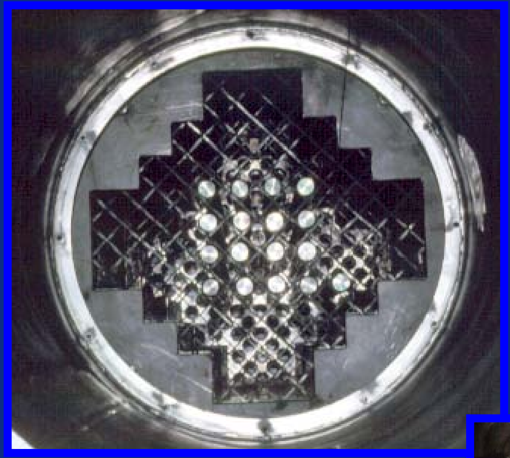


APEX Facility (USA) Description

Vessel Head & ADS 4 Lines

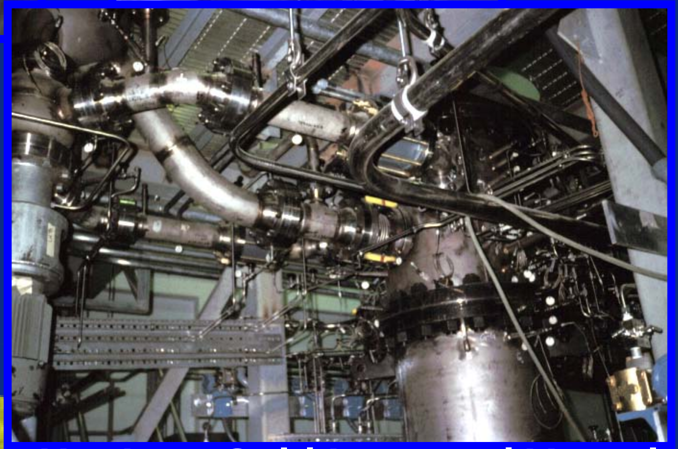


Core Heater Installation and Baffle



PZR & SG Head

Reactor Coolant Pumps



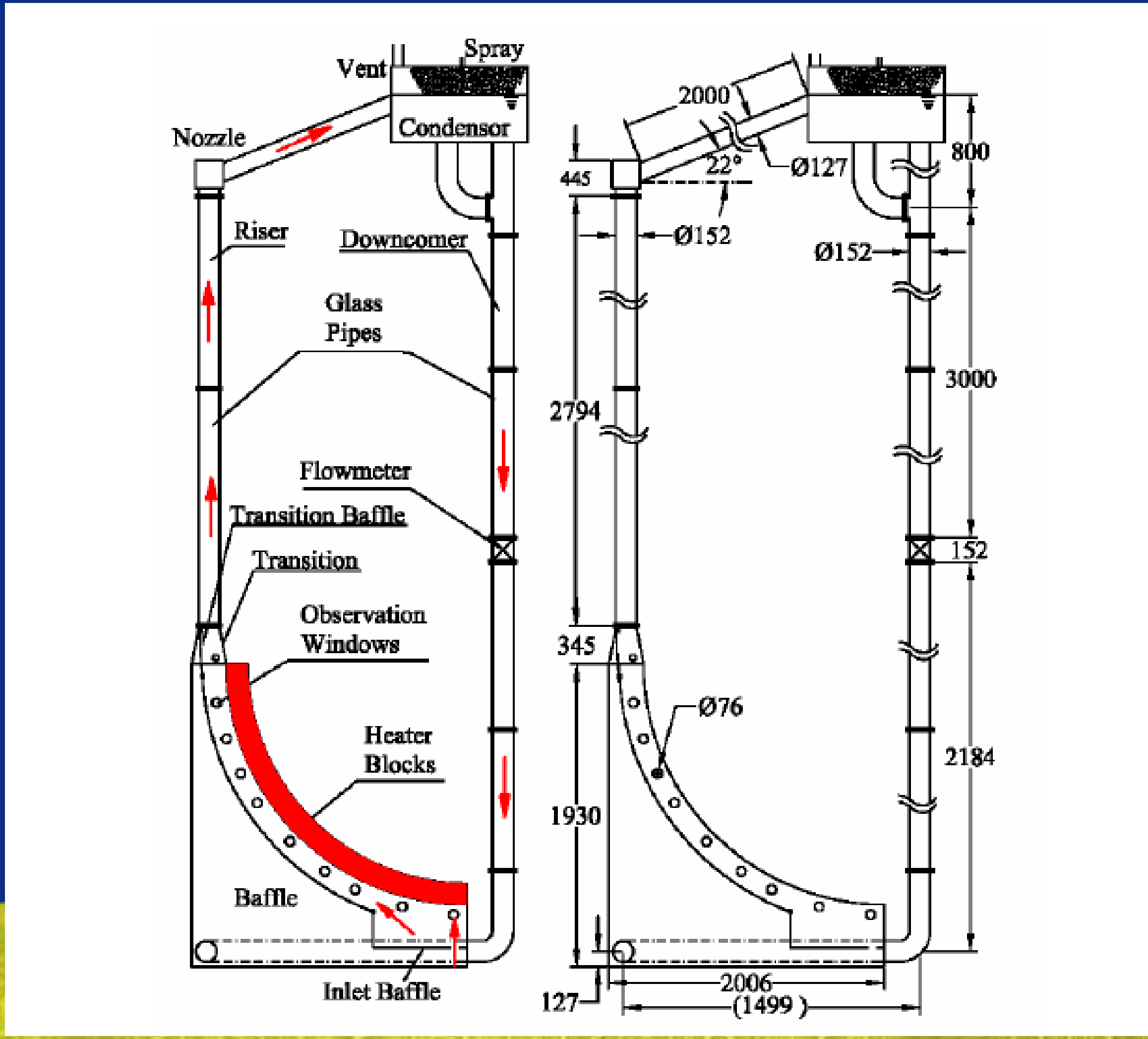
Hot Leg, Cold Legs and Vessel

Westinghouse

Large-Scale Heat Transfer PCS Test - USA

ULPU-2400 Config. V Full Scale Slice Testing

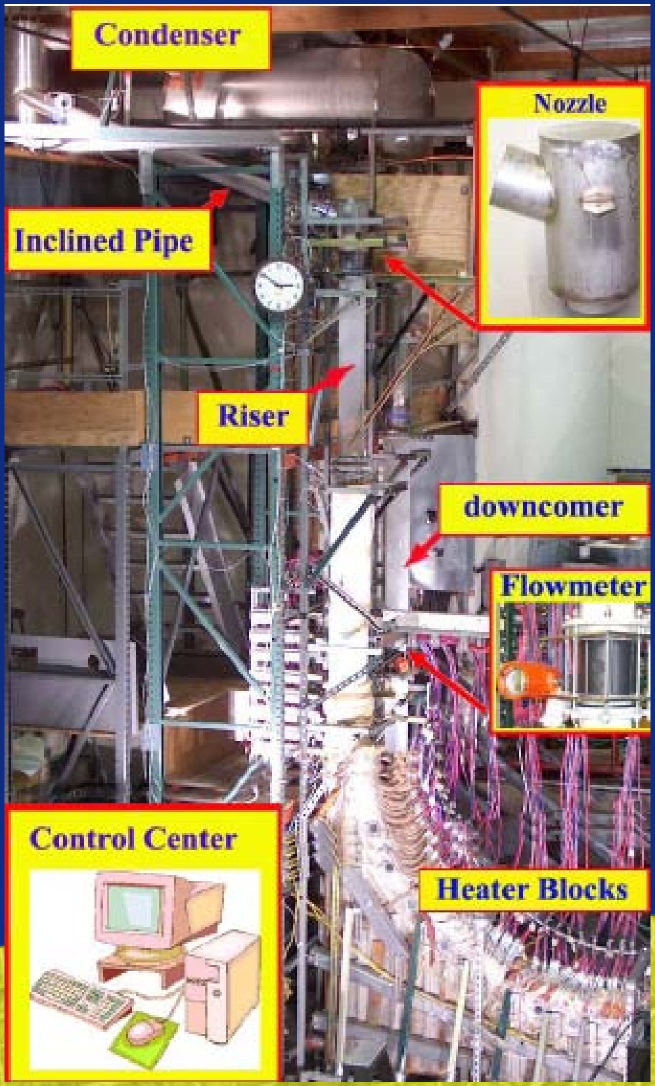
Confirms IVR Heat Transfer from Outside Reactor Vessel

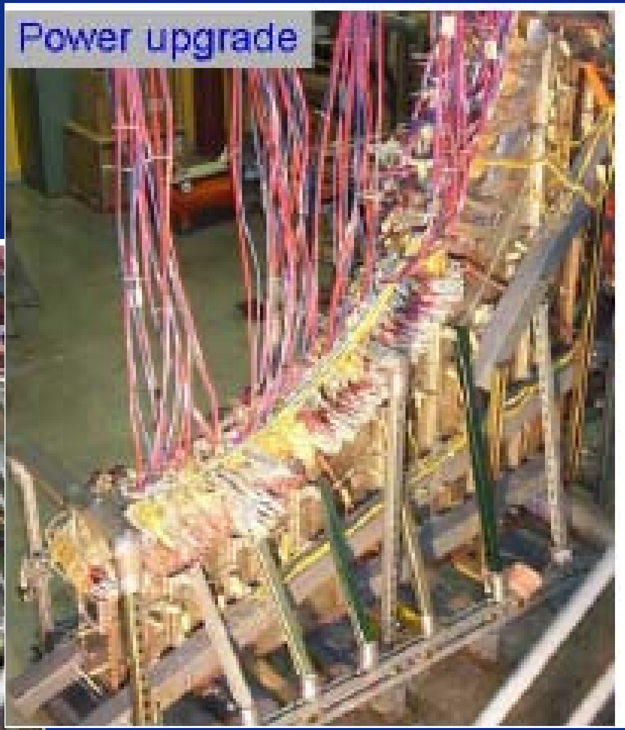


Westinghouse

ULPU-2400 Config. V Full Scale Slice Testing

Confirms IVR Heat Transfer from Outside Reactor Vessel

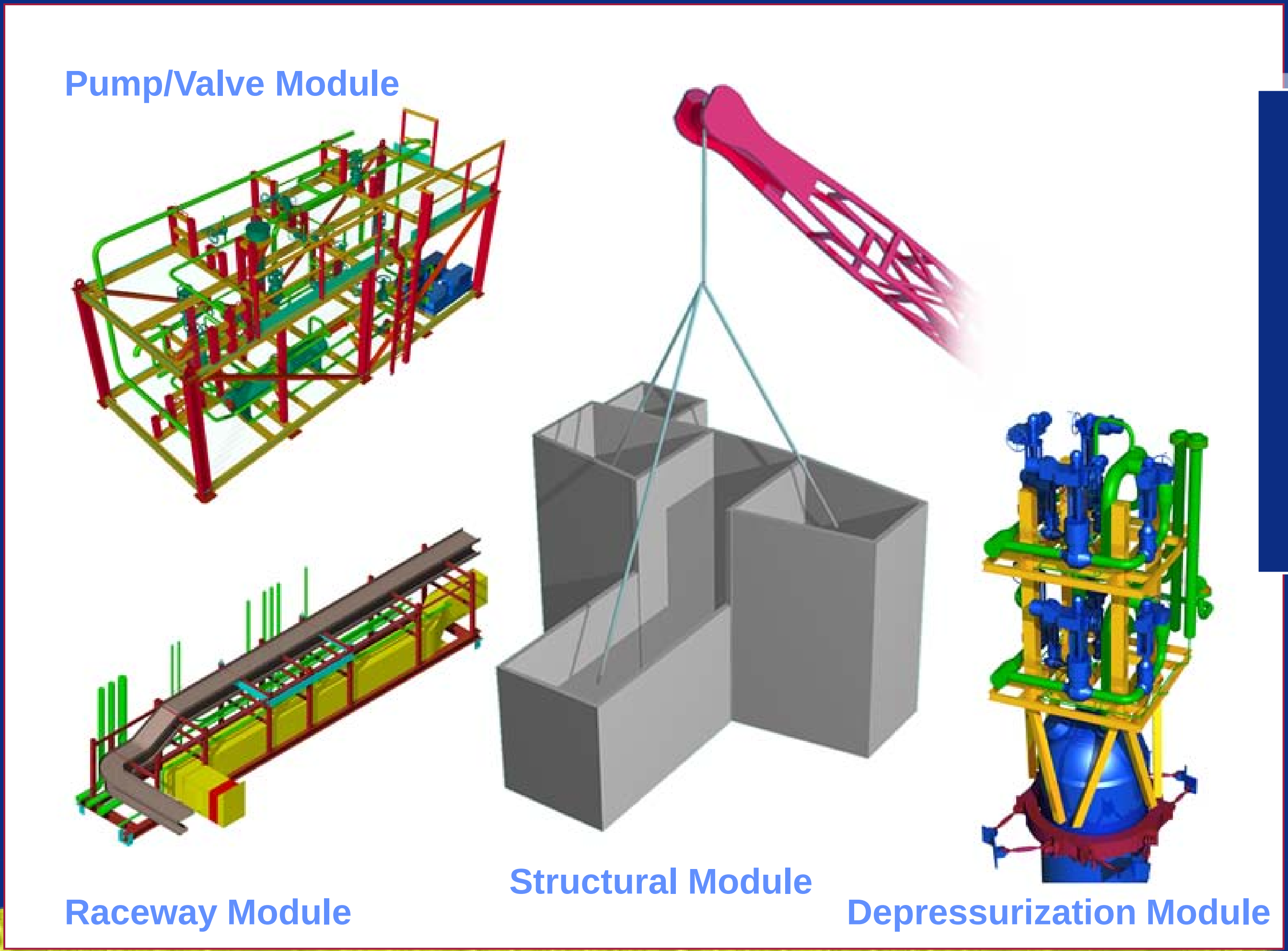




Westinghouse

AP 1000:
The Modular Construction

Modules Designed into AP1000 from the Beginning



Module Type	Number
Structural	122
Piping	154
Mechanical Equipment	55
Electrical Equipment	11
TOTAL	342

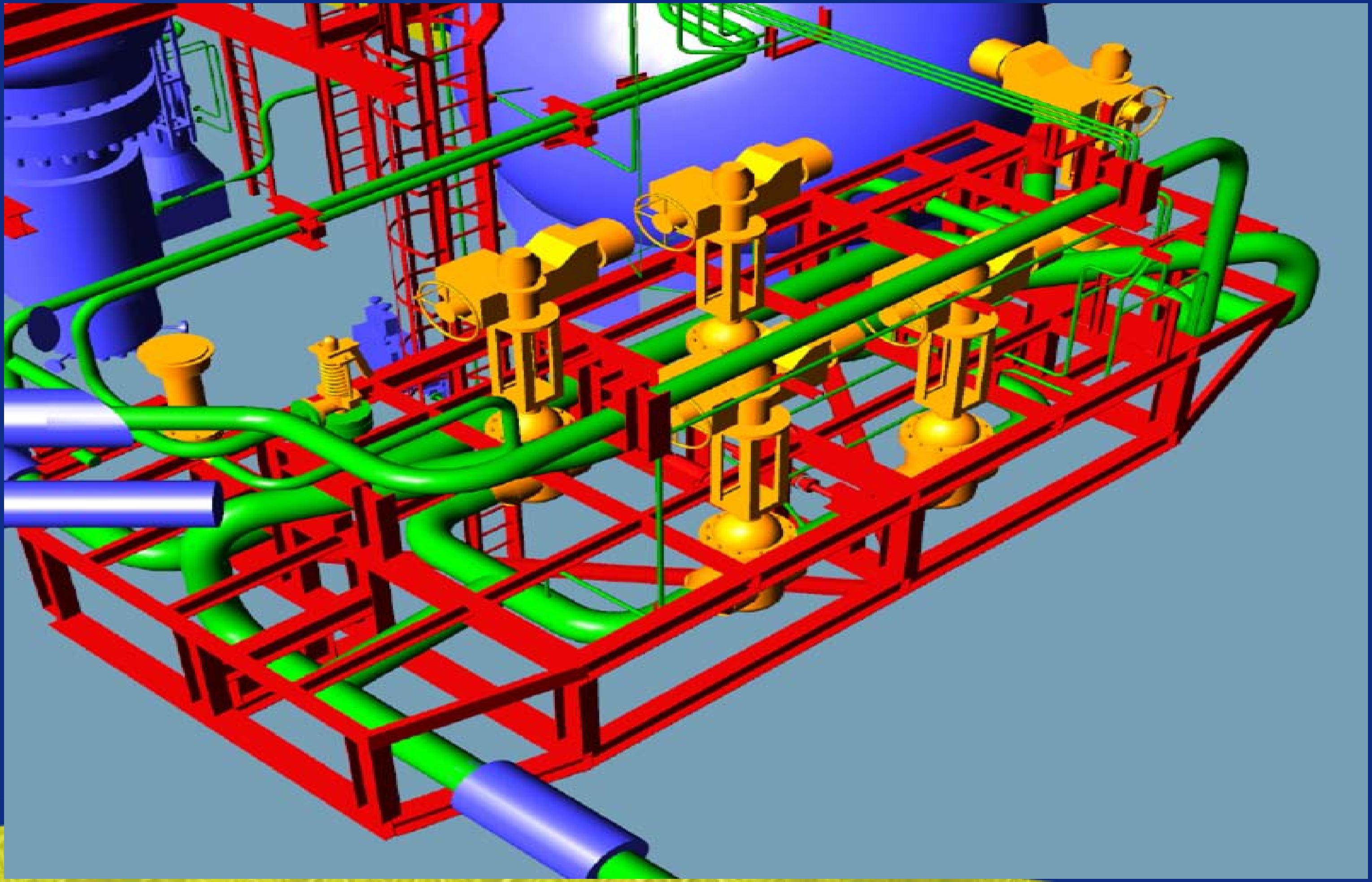
Westinghouse

Modularization – Impact on Construction

- Reduced calendar time, site labor and overall risk:
  - Module fabrication performed parallel with civil / structural work
  - Optimizes and levels manloading for mechanical and electrical work
  - Site congestion reduced
- Inspections performed at fabrication shop
- Reduced on-site work
- Concrete curing and coating time is drastically reduced

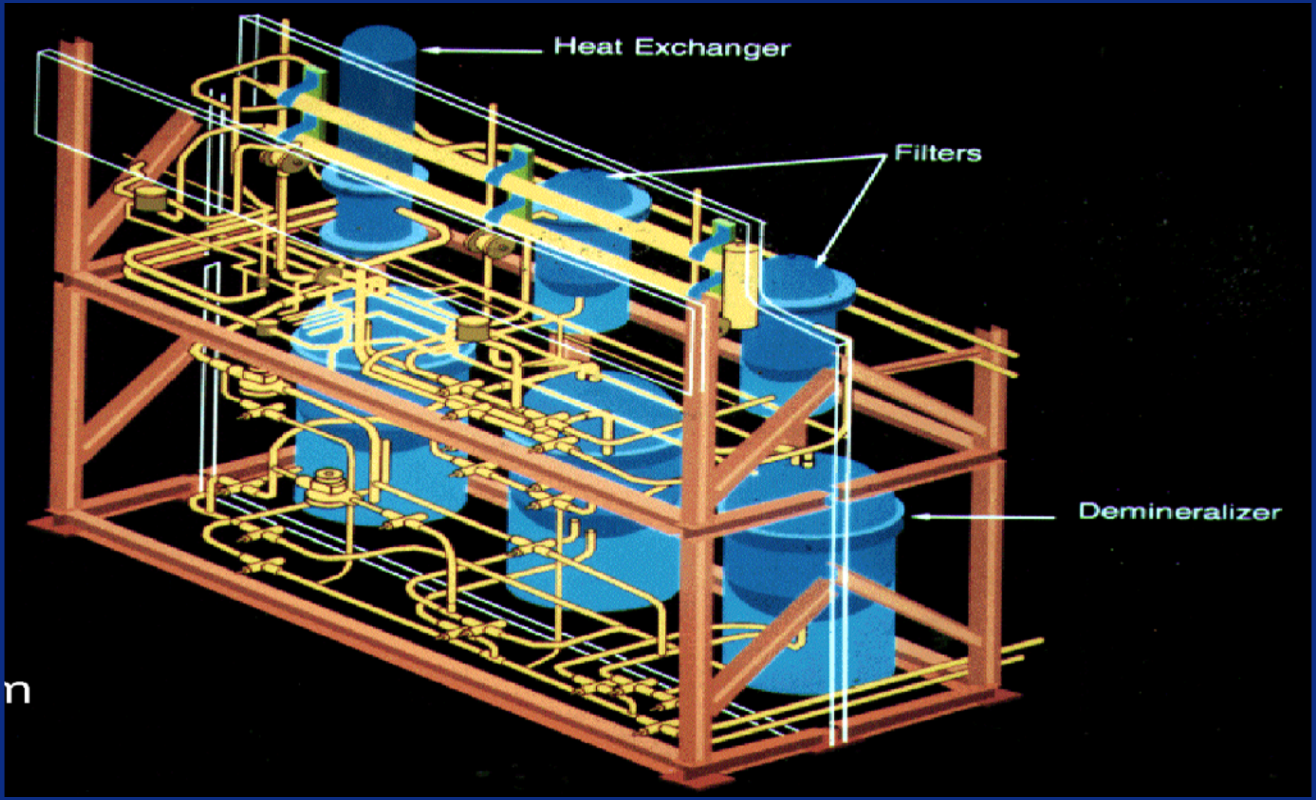
Westinghouse

Residual Heat Removal System - Pipe / Valve Module

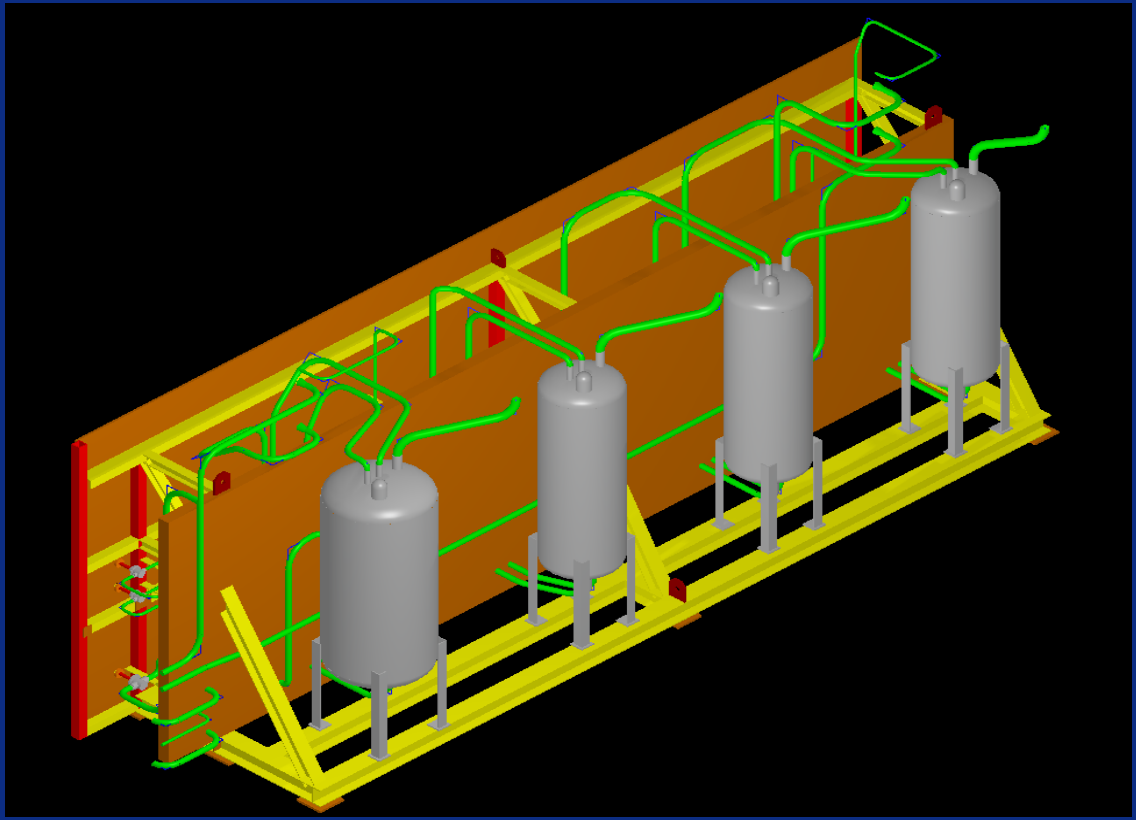


Westinghouse

Chemical and Volume Control System Equipment Module

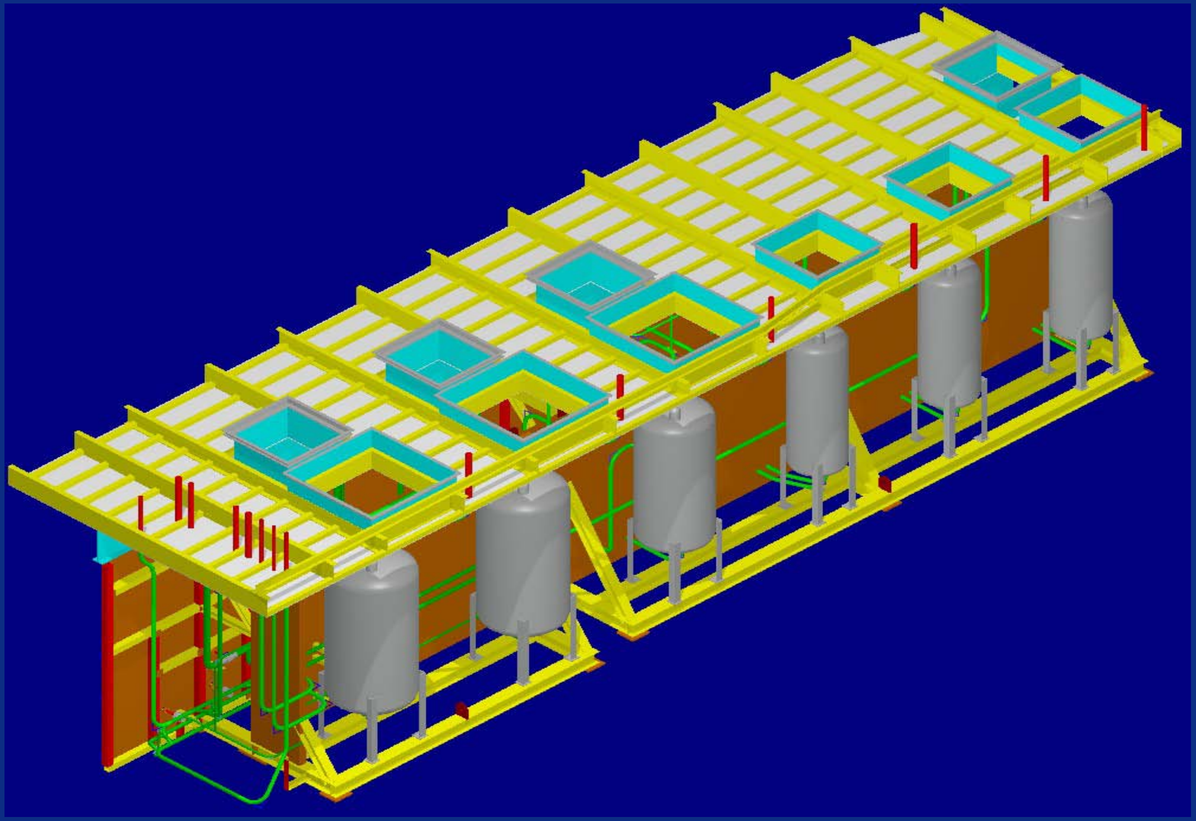


Waste System Demineralizers



Westinghouse

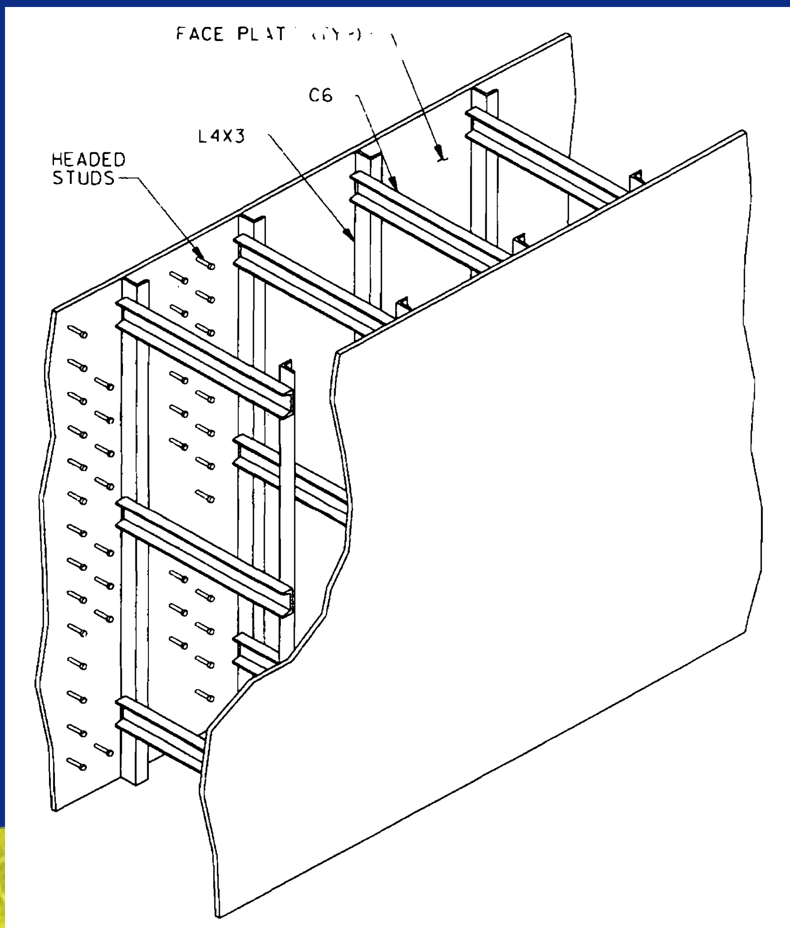
Integration Three Waste Modules



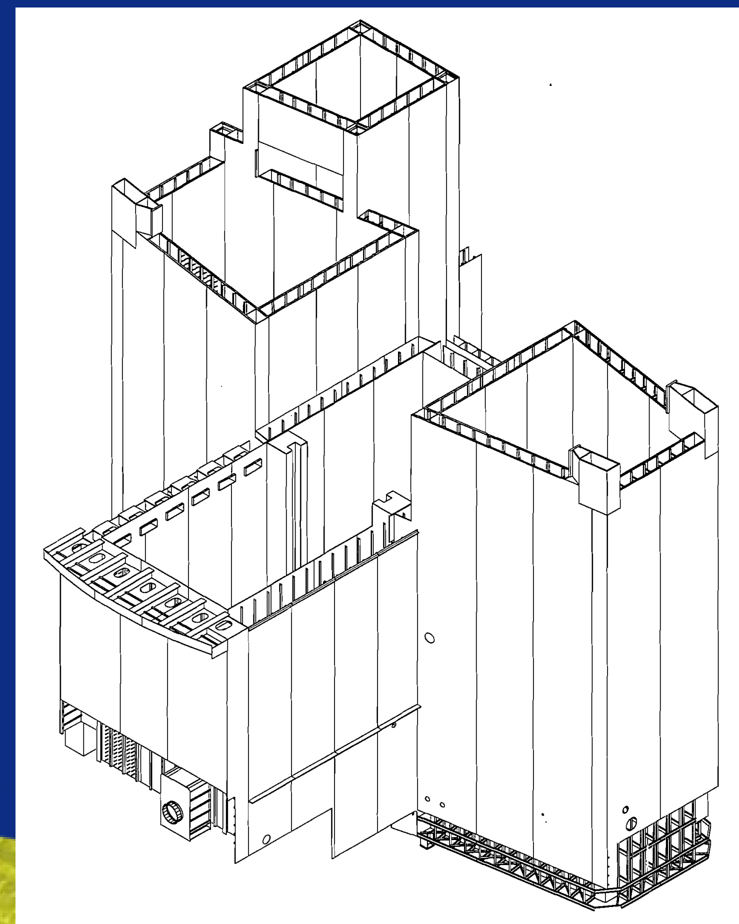
Westinghouse

Structural modules

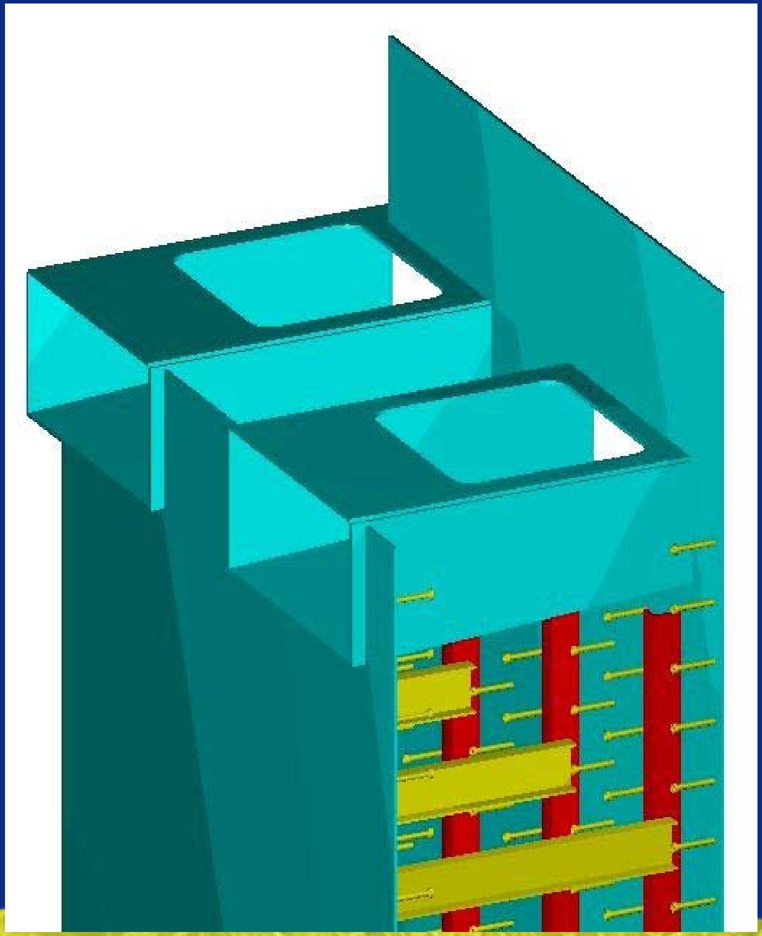
Truss Wall

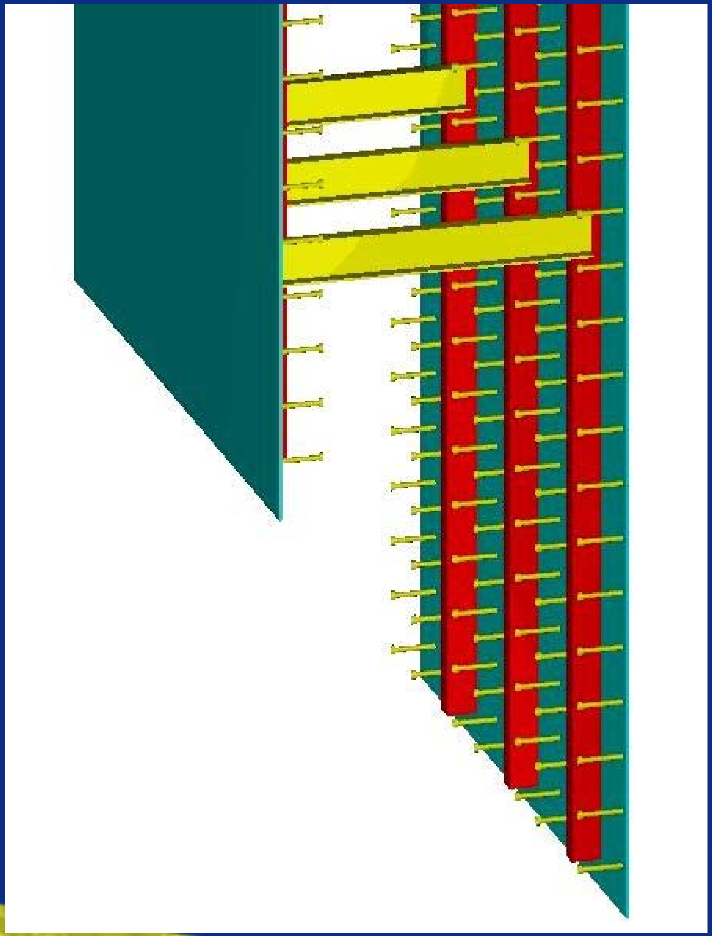


Structural



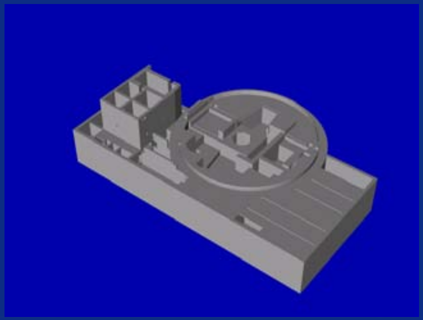
CA01 Submodule Details

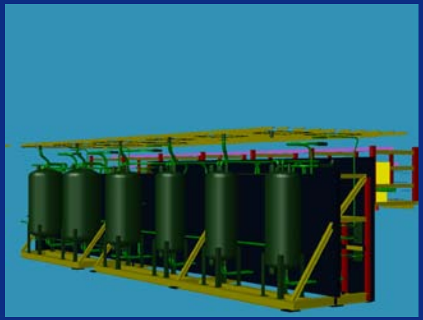


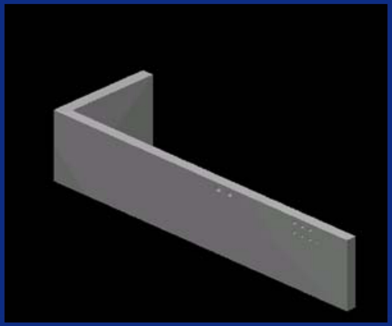


Schedule and Model Integration

Intergraph design review product
Primavera Project Planner
Continuing interactions with software vendor
3D model boundaries modified to match schedule activities
Link by activity
Activity construction durations maintained
Schedule improvements by logic changes only
Visualization capability for changing activity sequences

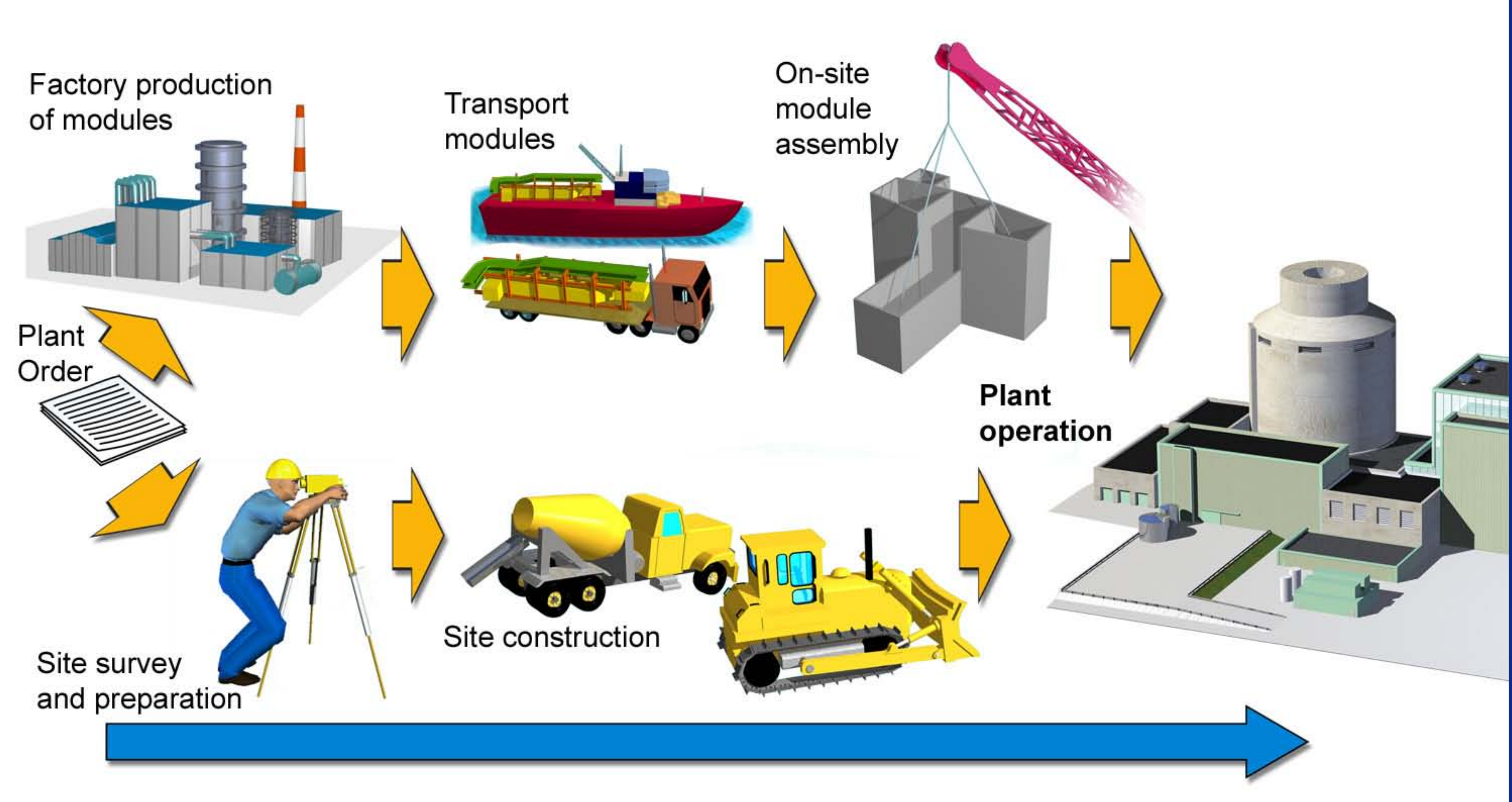






Westinghouse

Modular Construction Allows More To Be Done in Parallel
Result: Shorter Construction Schedule

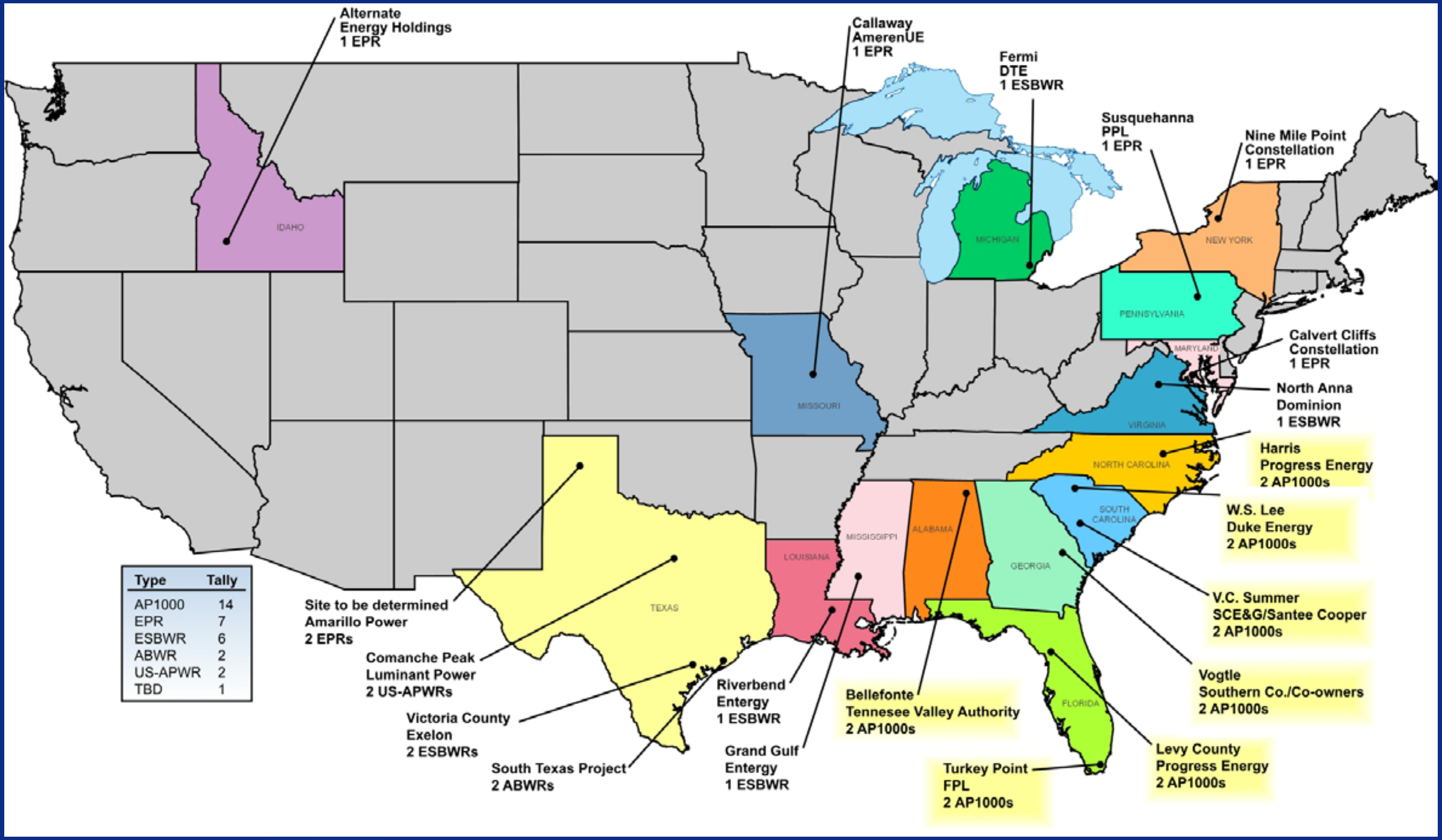


AP 1000:
Ten Plants Under Construcion
China and USA

Westinghouse

The Renaissance Is Here

New Reactor License Applications in U.S.



Source: NRC

The Renaissance Is Here

AP1000™ Projects in U.S.

14 AP1000 units selected by U.S. utilities to date

6 AP1000 units under contract

SCE&G

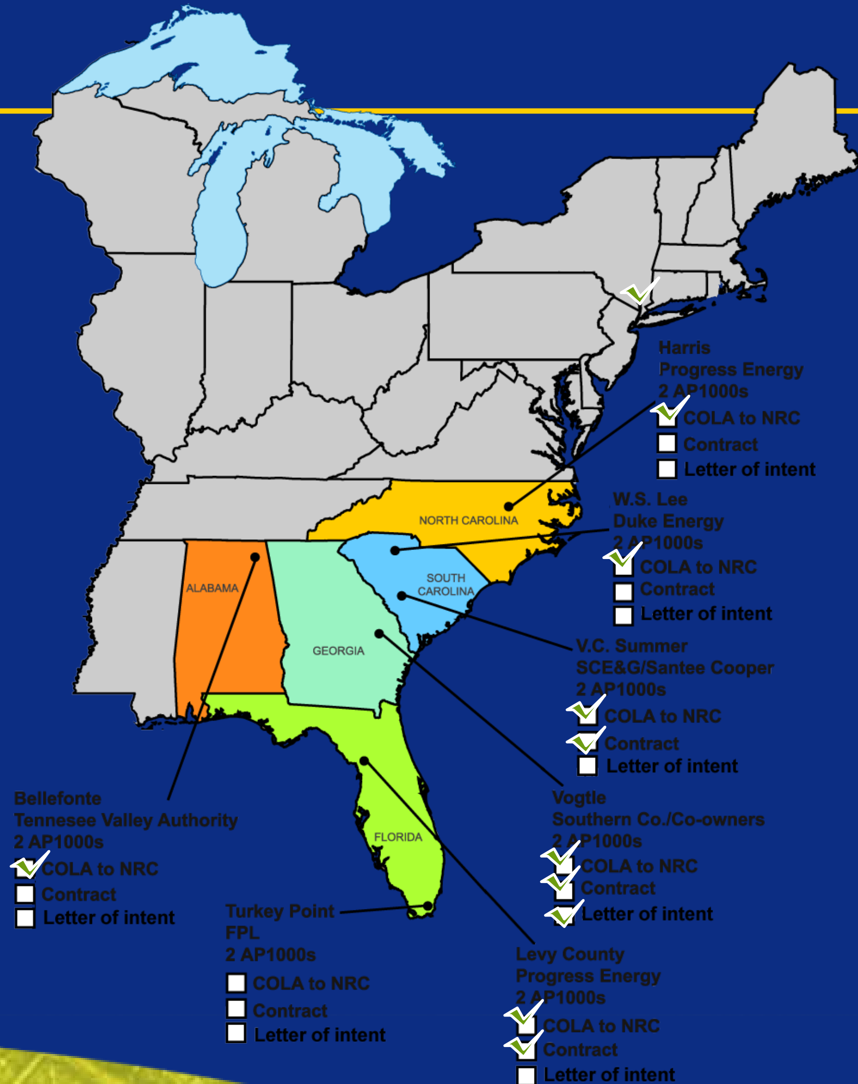
VC Summer 2	C.O.D. 4/1/2016
VC Summer 3	C.O.D. 1/1/2019

Southern Co.

Vogtle 3	C.O.D. 4/1/2016
Vogtle 4	C.O.D. 4/1/2017

Progress Energy

Levy County 1	C.O.D. 7/1/2016
Levy County 2	C.O.D. 7/1/2017



Westinghouse

AP1000 China Projects

Two units at Haiyang
Two units at Sanmen

Construction on Schedule

	Fuel Load	**COD**
Sanmen #1	May 2013	Nov 2013
Sanmen #2	Mar 2014	Sept 2014
Haiyang #1	Nov 2013	May 2014
Haiyang #2	Sept 2014	Mar 2015

Westinghouse

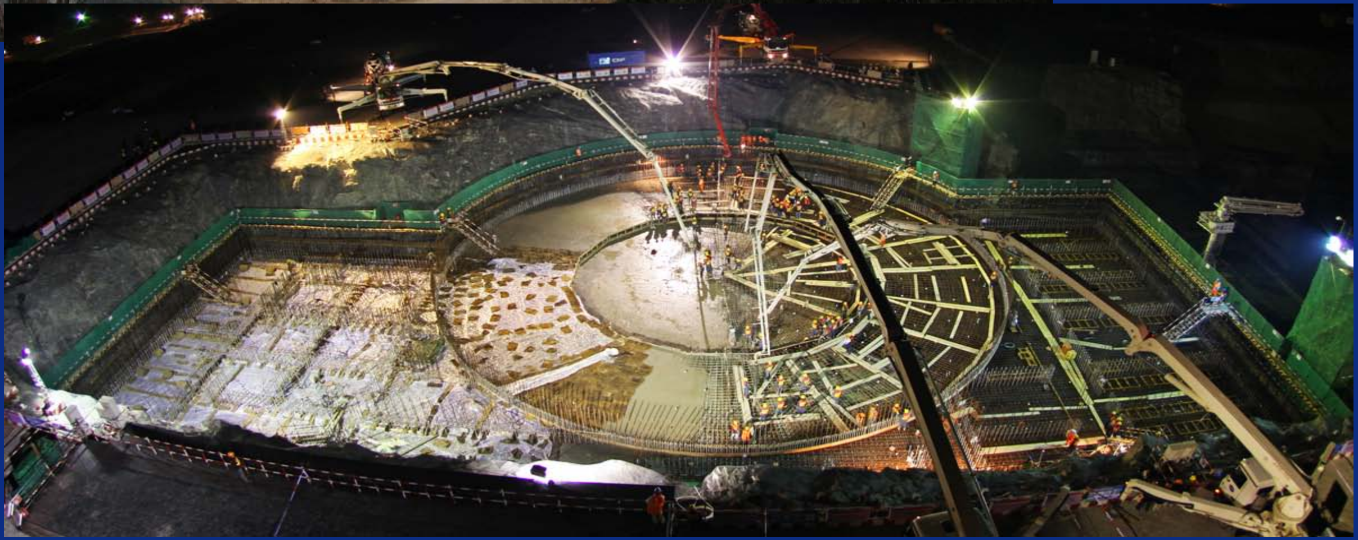
Status of Construction Milestones

- All four NI excavations have been completed
- Sanmen 1 First Concrete Milestone completed on schedule
- Successful setting of CA20
- Auxiliary Building walls started from 66’6” to 82’6”
- Manufacturing of heavy components is on schedule
- Valve development & Demonstration program on track
- Containment Vessel final assembly is occurring
- Reactor Coolant Pump build and test plan is on schedule
- All long lead forgings have been ordered and manufacturing is underway
- Module Factory in China was operational May 31, 2008

Westinghouse

The Renaissance Is Here

First AP1000TM Contracts in China



AP1000 - Sanmen First Concrete Pour

March 2009
Placement of the basemat concrete for Sanmen Unit 1 successfully ended March 31 after 46 hours and 58 minutes of continuously pouring 4,982 cubic meters of concrete.

Westinghouse

The Renaissance Is Here

First AP1000™ Contracts in China

Rotation of CA-20 Module – Sanmen 5 / 2009

Size (N x E x Height): 44'-0" x 68'-9" x 68'-0"
Weight: 1,717,800 lbs.

Westinghouse

The Renaissance Is Here

First AP1000™ Contracts in China

June 29, 2009

Westinghouse

U.S. AP1000™ Projects: Project Update

Vogtle Units 3 & 4 Project Update

- Project is implemented
  - Westinghouse and Shaw Home Offices are staffed, initial systems and procedures are in place, and implementing Project per schedule
  - Site mobilized and early phases of construction are underway
- PSC certification approved March 17, 2009
- Full Notice to Proceed received from Southern Nuclear Company on March 31, 2009
- 17 of 19 early procurements have been placed (remaining two will be placed by August 2009)

Westinghouse

U.S. AP1000™ Projects: Project Update

Vogtle Units 3 & 4 Project Update

- Construction
  - Issued Notice of Commencement
  - Continued site mobilization, temporary trailers installed, subcontractors mobilized
  - Construction access road completed
  - Interim security control established
  - Runoff ponds complete, 100-year run-off ditch relocated
  - Preparing for plant site excavation

Westinghouse


Vogtle 3 &4
March 23 – 30, 2009

U.S. AP1000™ Projects: Project Update

VC Summer 2 & 3 Project Update

- **Activities**
  - PSC certification of project approved February 11, 2009
  - Continuing site preparations including construction access road completion, installation of catch basins, development of lay-down areas, construction city development and rail spur rough grading
  - Placed purchase orders for major components including steam generators, reactor vessel, reactor coolant pumps, containment vessel, turbine generator, pressurizer, reactor coolant piping, reactor vessel internals and CRDMs

Westinghouse

U.S. AP1000™ Projects: Project Update

VC Summer 2 & 3 Project Update

- **Activities (continued)**
  - Issued project schedule performance baseline April 1, 2009
  - Initiated grading plant access road and the turn lanes at the intersection of Parr Road with State Highway 213 (main access to site)
  - Received State Regulatory approval to start clearing and grading the table top in preparation for excavation (Phase 3A permit)
- **Upcoming Work**
  - Commence table top grading in May 2009
  - Complete rail spur installation in June 2009
  - Complete new hire and admin. support buildings in September 2009
  - Complete Mayo Creek bridge construction Jan. '10

Westinghouse

U.S. AP1000™ Projects: Project Update

Levy County 1 & 2 Project Update

- "Determination of Need" petition unanimously approved by Florida PSC in July 2008
- Levy County 1 & 2 COLA submitted by Progress Energy to NRC on July 30, 2008
- EPC contract signed on December 31, 2008

Westinghouse

U.S. AP1000™ Projects: Project Update

Levy County 1 & 2 Project Update

- Consortium home office teams have been assembled and are fully engaged with Progress Energy
- Long-lead procurement of major components commenced in 2008
- Progress Energy notified consortium on April 30, 2009 of partial suspension of work
- On August 13, 2009 Progress Energy received state site certification from the Florida Power Plant Siting Board
- Expect to receive an NRC combined construction permit-operating license in late 2011 or early 2012

Westinghouse

AP 1000
The Renaissance Has Started!

THANKS

Westinghouse