GE Nuclear Energy

ESBWR Design, Technology and Program Plan Overview

A.S. Rao

NRC Staff - GE Meeting
June 20 and 21, 2002
Rockville, Maryland

Purpose of Meeting

- ***Provide ESBWR background information to NRC staff***
  - Issues to be resolved during pre-application review
    - Adequacy of testing, analysis methodology approval, SSAR details
  - Reference design
  - Testing and technology basis
  - Analysis methodology, qualification and application approach
  - Information on submittals to be made in August/Sept 2002
- ***Obtain NRC feedback***
  - Overall approach
  - Identification of additional information needed by NRC for completing pre-application review
  - Schedule and steps for reaching agreement on pre-application review scope, schedule and cost and overall plan

Agenda for ESBWR Meetings June 20/21, 2002

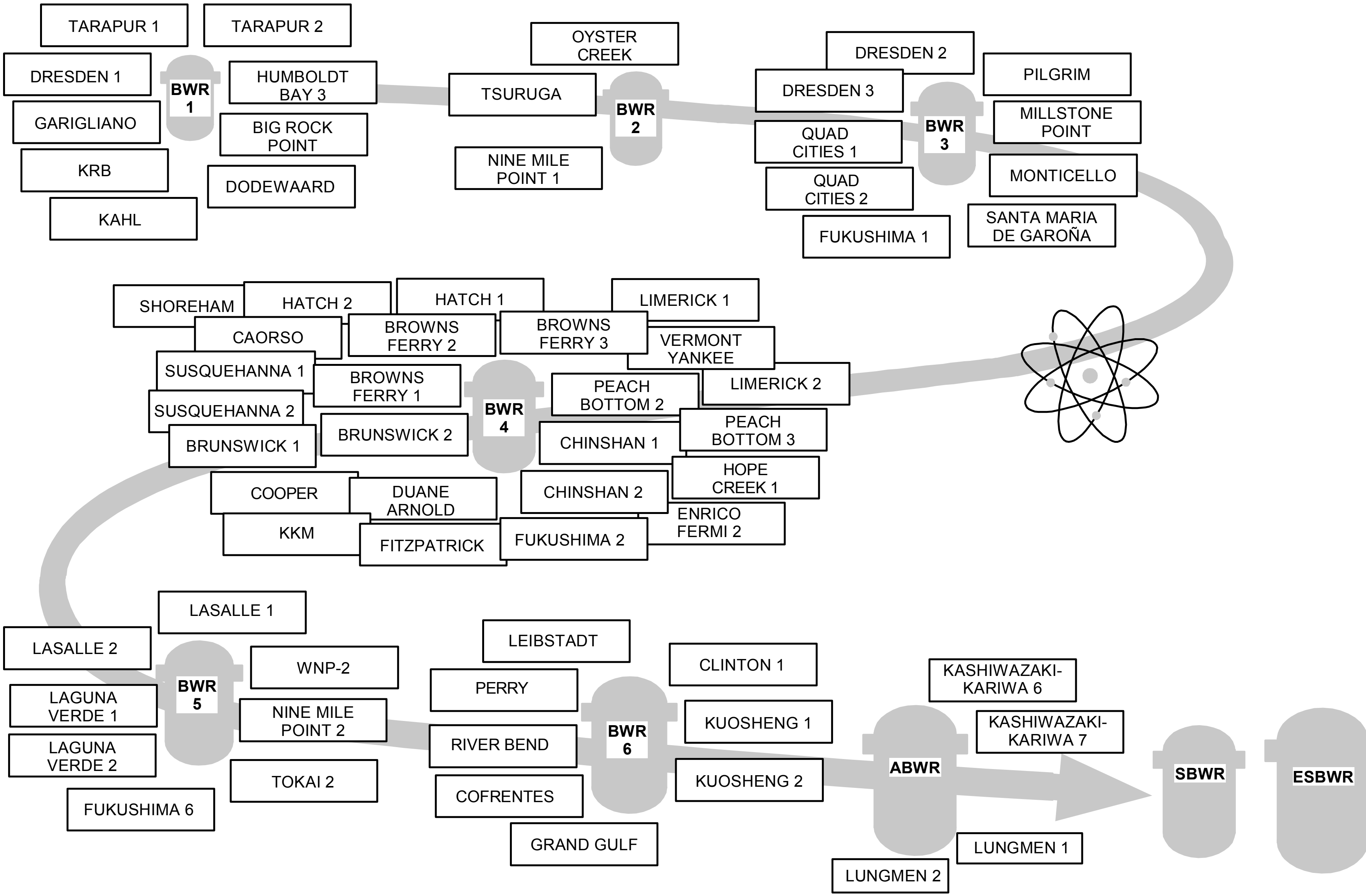
- ***Introduction and overview***
  - Pre-application plan
- ***Design description***
  - Passive safety systems
- ***Plant performance***
- ***Technology basis***
  - Testing and analysis program
  - Testing program overview
  - Scaling
  - Methodology, qualification and application
- ***Summary and Conclusion***

Enhanced performance and economics and a solid technology basis provide confidence in the design

Outline – Introduction and Overview

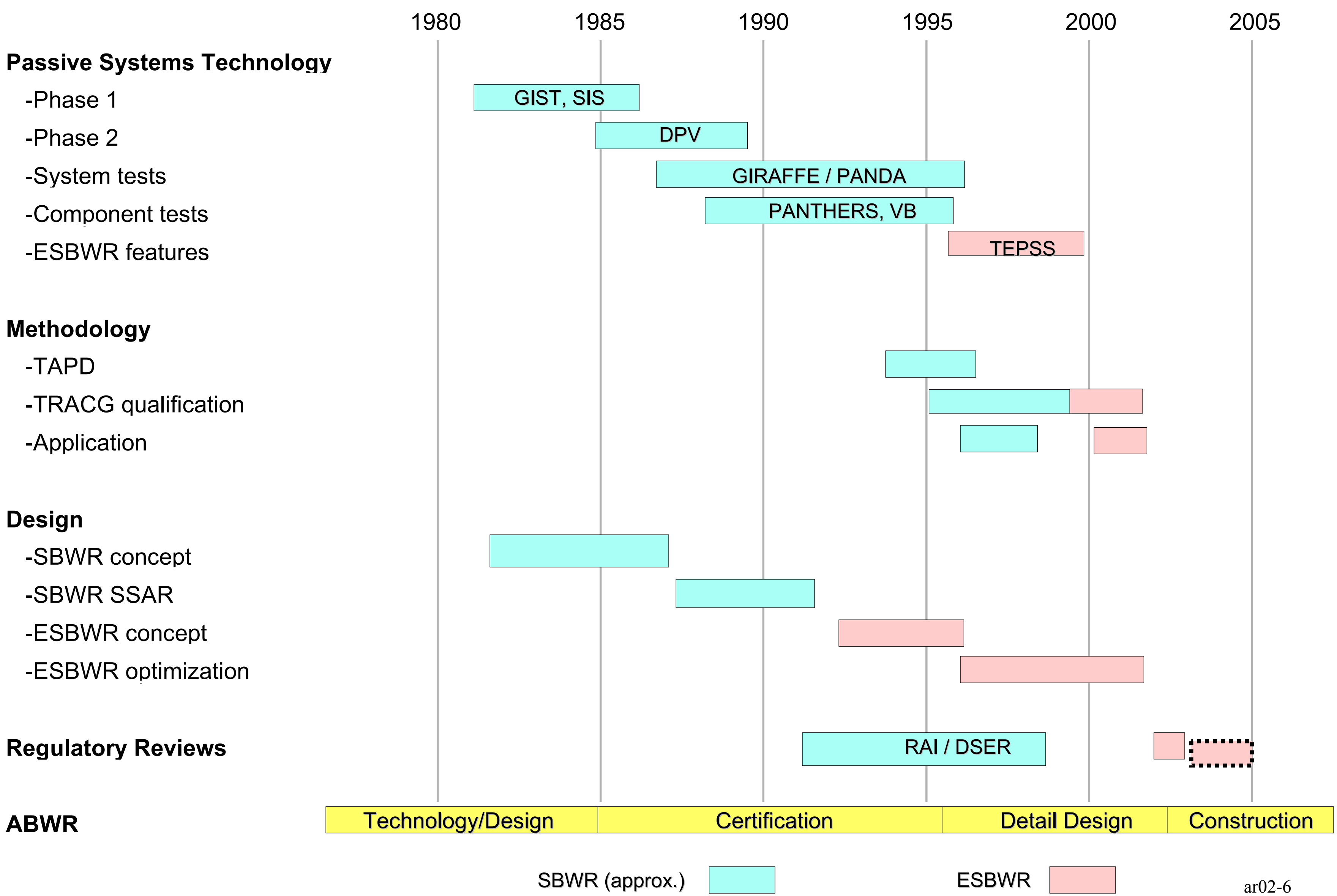
- ***History of ESBWR development***
- ***Design summary***
- ***Passive safety systems***
- ***Plant performance***
- ***Technology basis***
- ***Pre-application plan***
- ***Summary and Conclusion***

12 month plan to obtain cost and schedule for ESBWR certification



Evolution of the BWR

ESBWR History – showing inter-relationship to SBWR program (a program to enhance plant performance and economics)

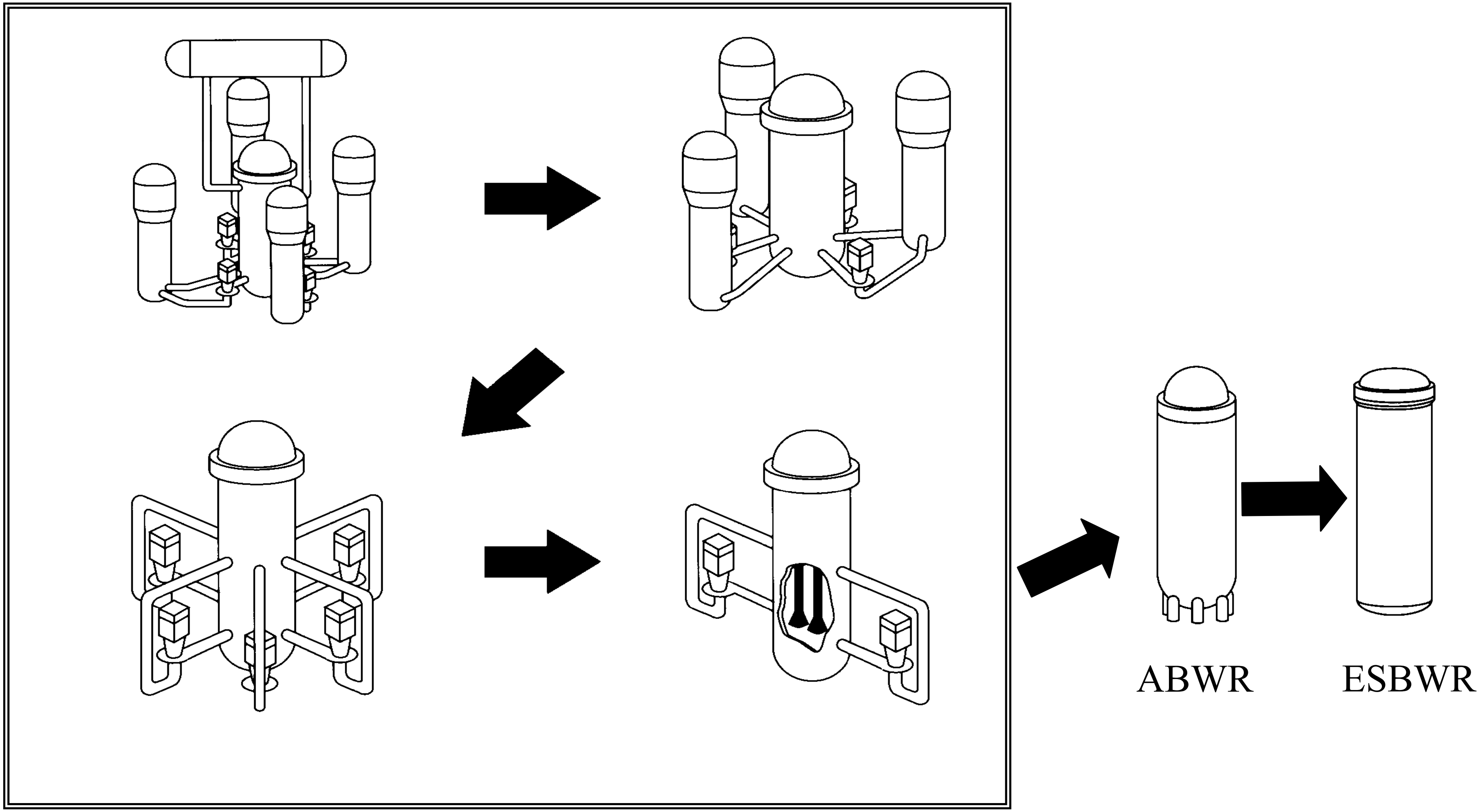


ar02-6

Outline

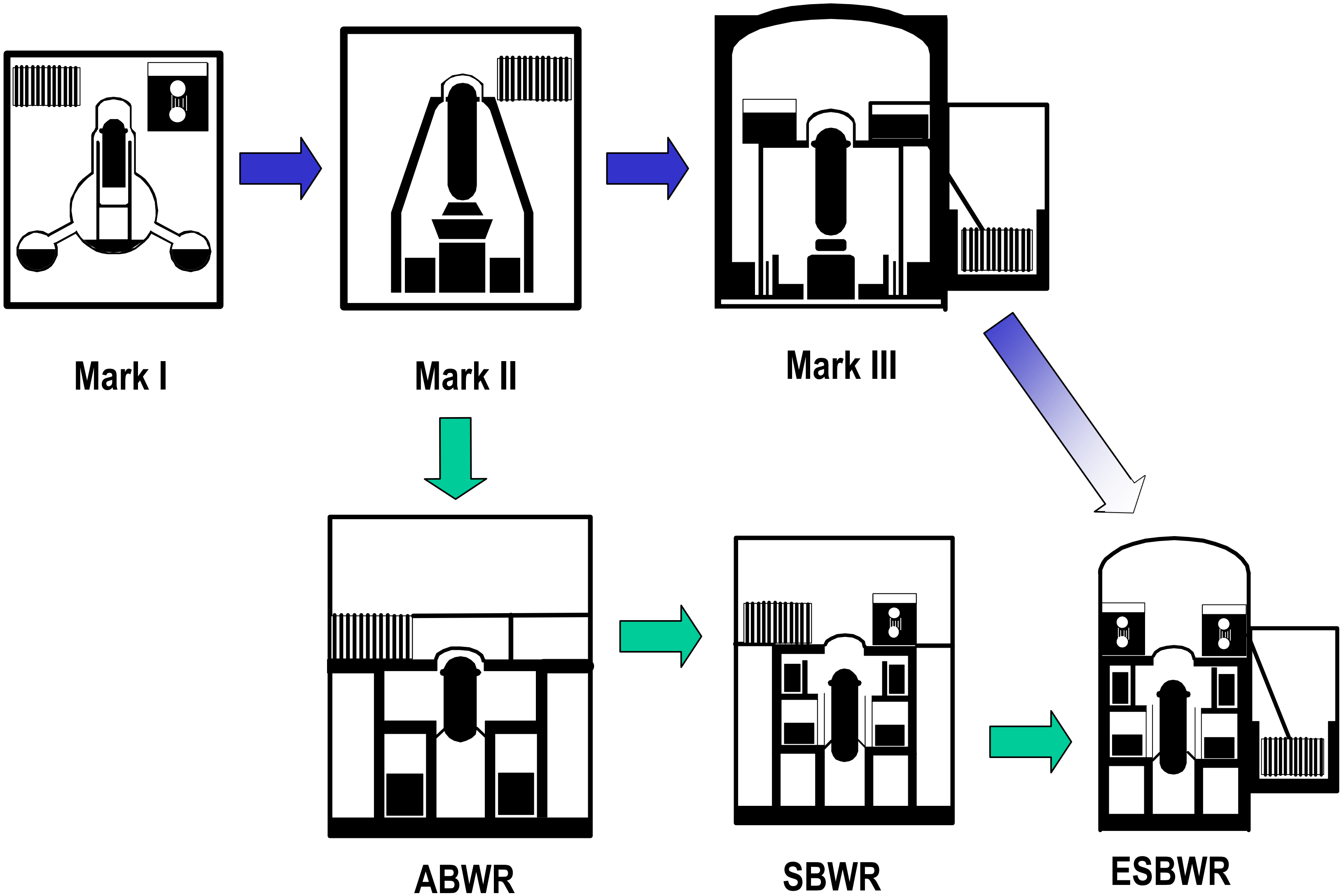
- *History of ESBWR development*
- ***Design summary***
- *Passive safety systems*
- *Plant performance*
- *Technology basis*
- *Pre-application plan*
- *Summary and Conclusion*

Evolution of the ESBWR Reactor Design



Evolution and Innovation Towards Simplicity

Evolution of BWR Containments



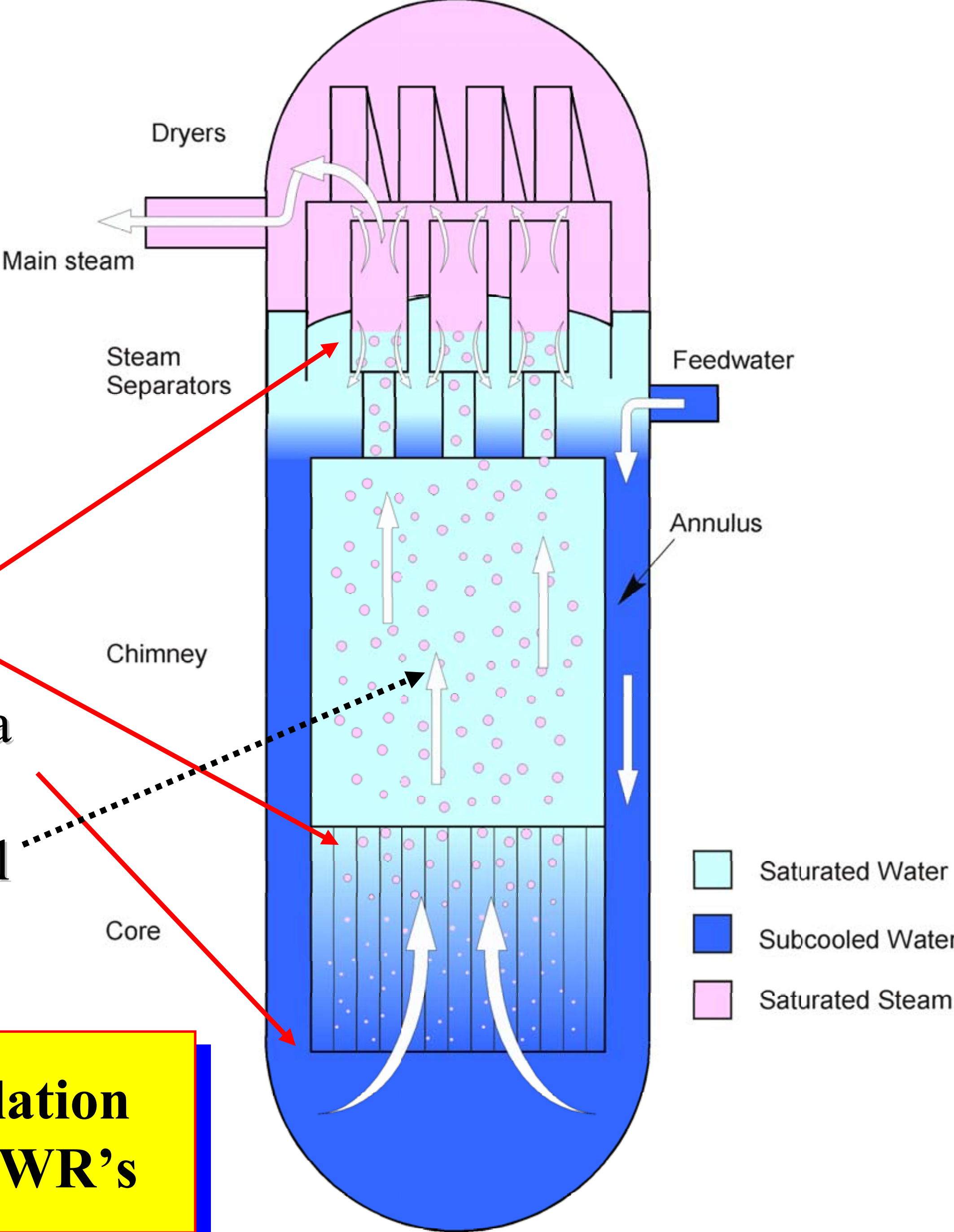
Evolution and Innovation Towards Simplicity

Comparison of Key Parameters

Parameter	BWR/4-Mk I (Browns Ferry 3)	BWR/6-Mk III (Grand Gulf)	ABWR	ESBWR
Power (MWt)	3293	3833	3926	4000
Power (MWe)	1098	1290	1350	1380
Vessel height (m)	21.9	21.8	21.1	27.7
Vessel diameter (m)	6.4	6.4	7.1	7.1
Fuel Bundles (number)	764	800	872	1020
Active Fuel Height (m)	3.7	3.7	3.7	3.0
Power density (kw/l)	50	54.2	51	54
Number of CRDs	185	193	205	121

Evolution towards simplicity within a small range

- Reduced flow restrictions
  - improved separators
  - shorter core
  - increase downcomer area
- Higher driving head
  - chimney and taller vessel



Enhanced Natural Circulation Compared to Standard BWR's

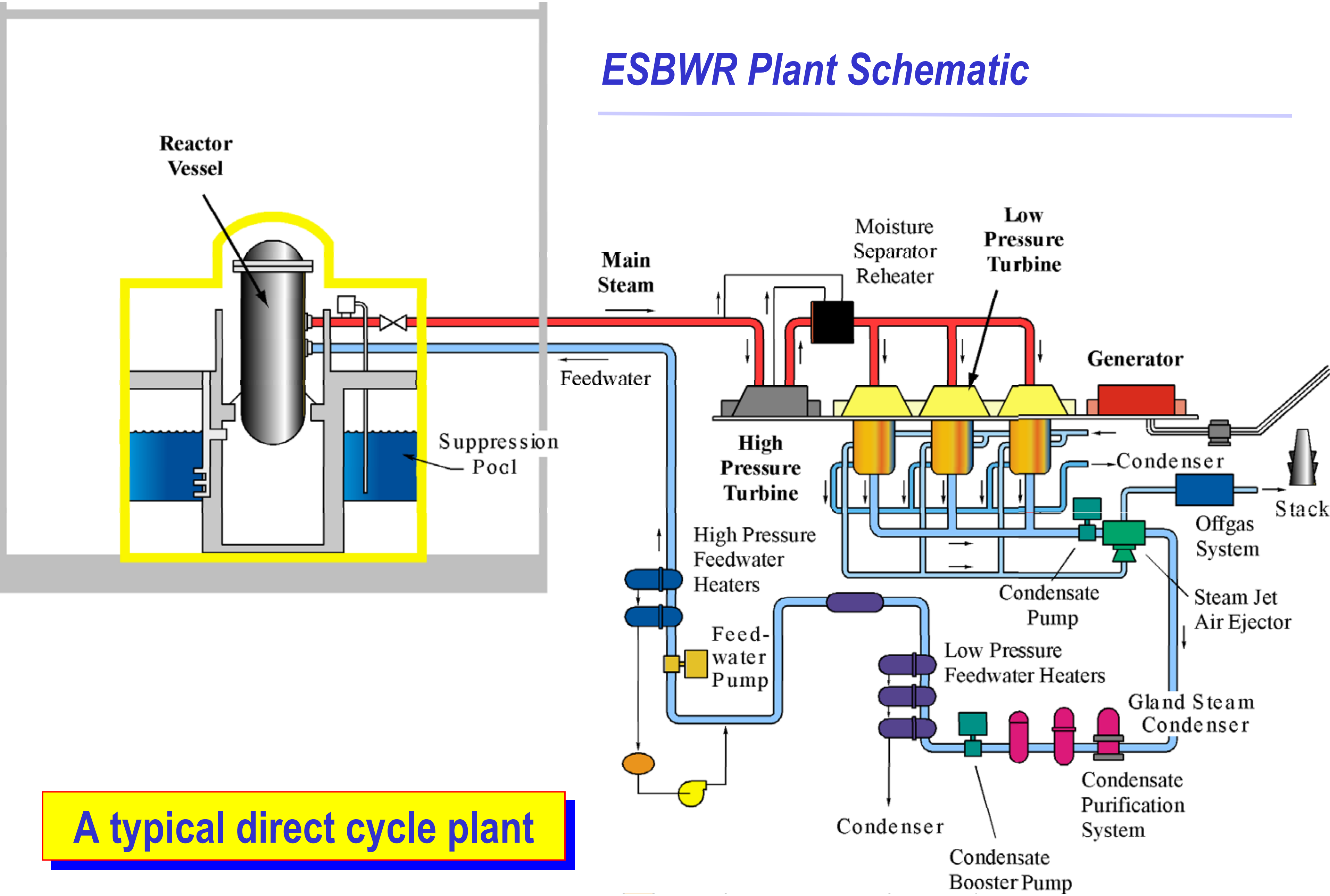
Natural Circulation

- ***Reduction in Components***
  - pumps, controls, power supplies
  - vessel internals
  - control rod drives

- ***Very Good Performance and Reliability***
  - power/flow ratio same as pumped plant at rated power
  - large margin to stability

Simplified systems improve plant reliability

ESBWR Plant Schematic



A typical direct cycle plant

Outline

- History of ESBWR development
- Design summary
- **Passive safety systems**
- Plant performance
- Technology basis
- Pre-application plan
- Summary and Conclusion

Passive Safety Systems

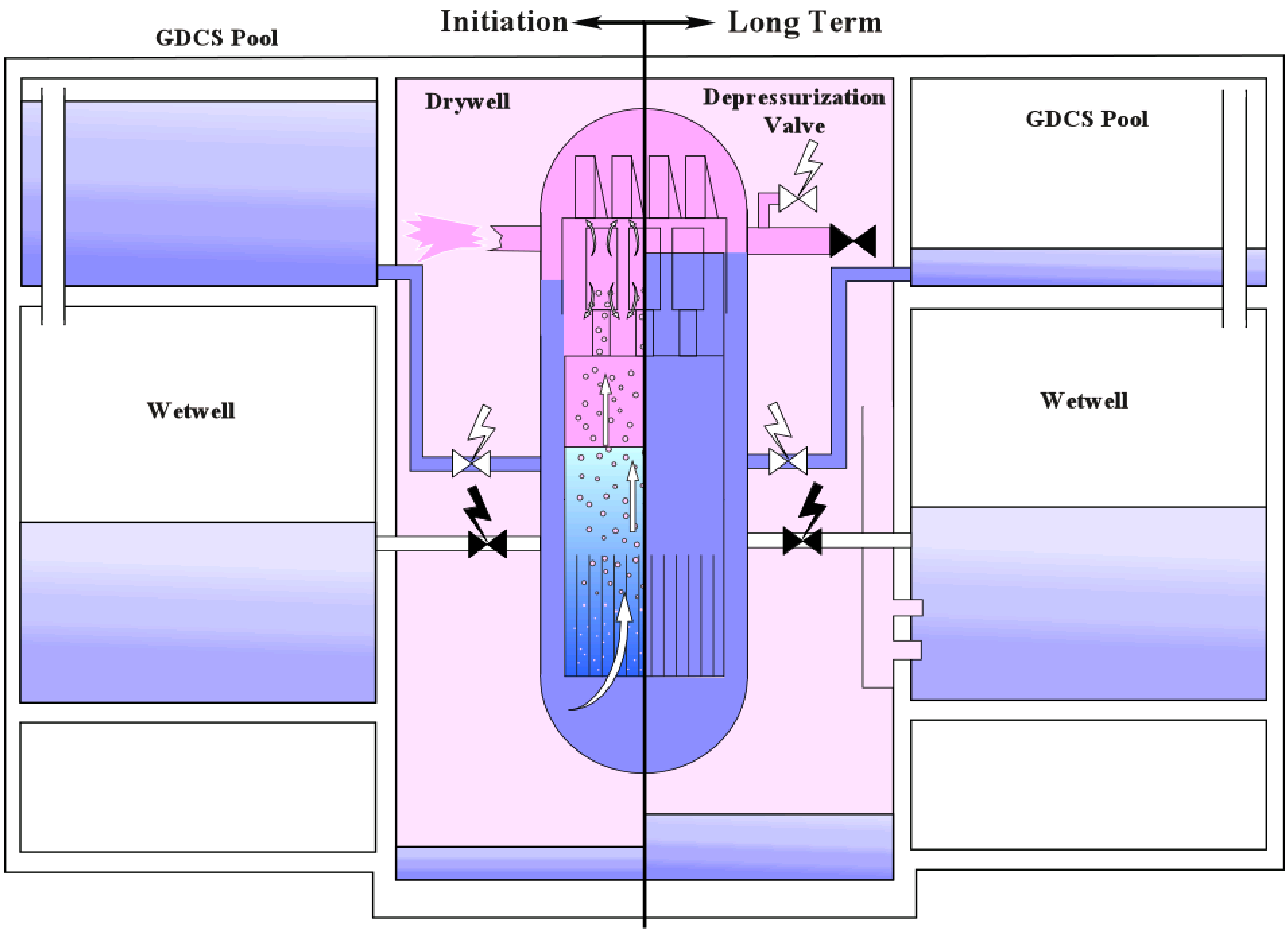
- ***Reactivity Control***
  - **Accumulator driven scram system**
  - **Accumulator driven backup boron injection system**
- ***Inventory Control***
  - **Taller vessel with additional inventory**
  - **High pressure isolation condensers (IC)**
  - **Depressurization and gravity driven cooling system (GDCS)**
- ***Decay Heat Removal***
  - **Isolation condensers for transients and station blackout**
  - **Pressure suppression system for blowdown energy**
  - **Passive Containment Cooling System (PCCS) for breaks**
    - Decay heat removal capability for 72 hours without operator action
    - Simple actions extend capability beyond 72 hours
    - Plant recovery actions expected in 24 hours
    - Containment overpressure system (COPS) – defense in depth

Simplified Systems Using Operating Plant Technology

Basic safety system design criteria – maintain water inventory

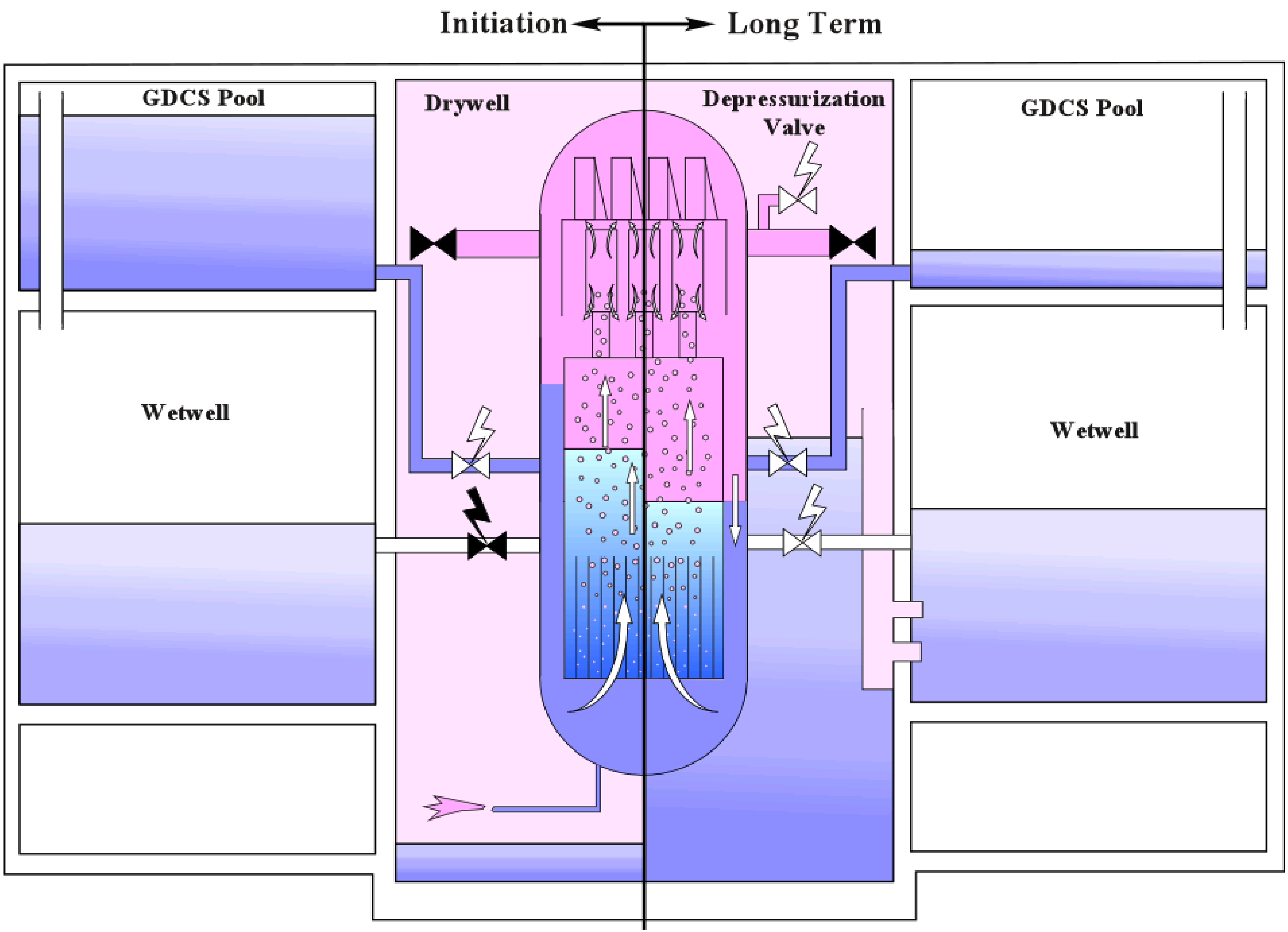
- ***Increase inventory in the vessel***
  - **Use taller vessel**
  - **Increase amount of subcooled water**
- ***Minimize inventory loss from the vessel***
  - **Eliminate large pipes below the core and minimize other pipes**
  - **Use saturated systems with typical BWR pressure for normal operation**
- ***Keep core covered after initial blowdown***
  - **Shorter core lower in the vessel**
- ***Provide Inventory Makeup***
  - **Required makeup rate is very low**
    - Multiple tanks rely on gravity
  - **No high capacity systems needed**
  - **Fewer systems result in minimal system interaction**

Gravity Driven Cooling System (GDCS) - Main Steam Line Break



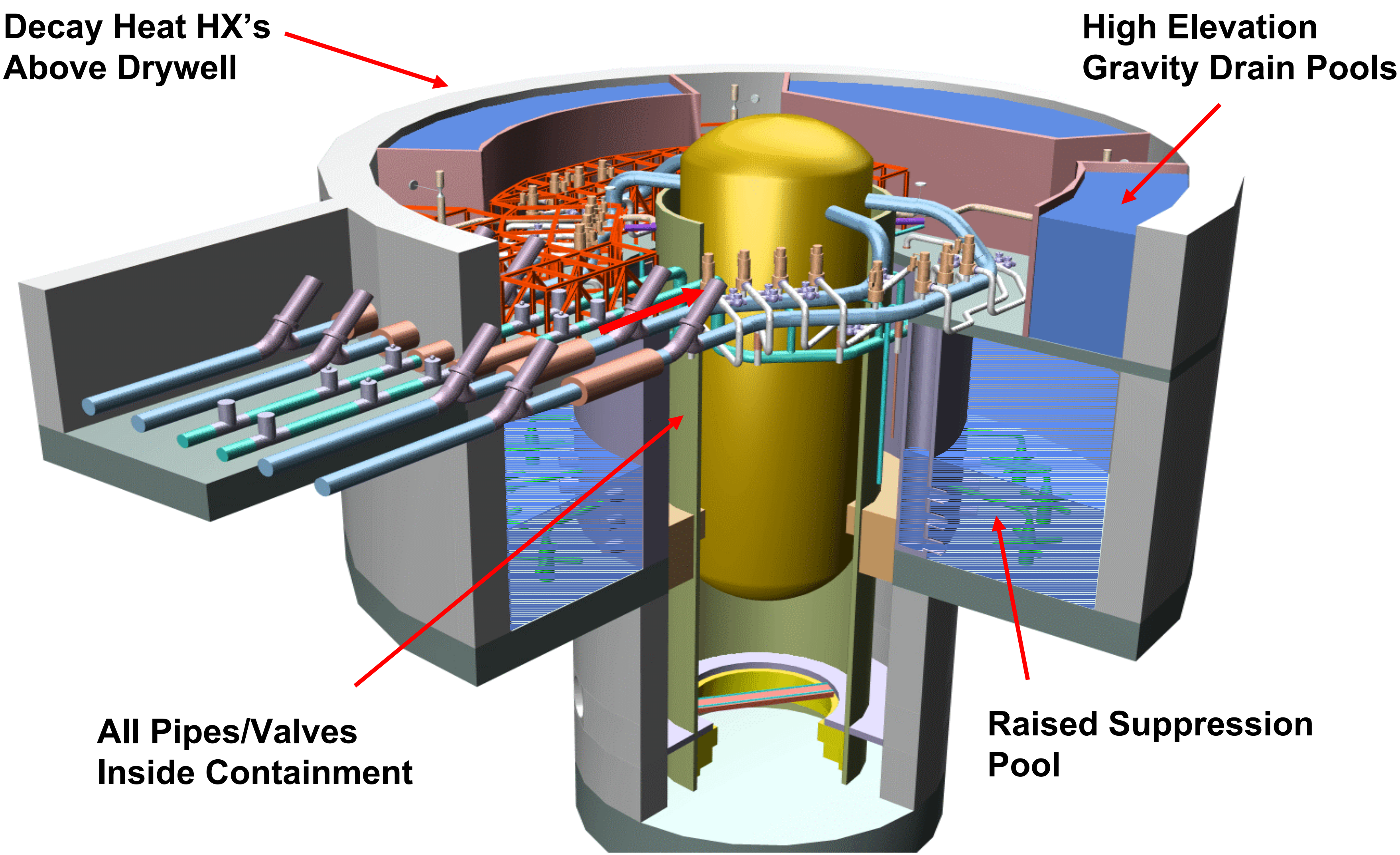
ar02-17

Gravity Driven Cooling System (GDCS) - Small Pipe Break, Vessel Bottom



ar02-18

Safety Systems Inside Containment Envelope



Decay Heat Removal

- ***From the vessel - no pipe break***

- ***From the containment***
  - **no break**
  - **small leak**
  - **large break**
  - **severe accident with hydrogen**

Concept is simple and evaluation is straightforward

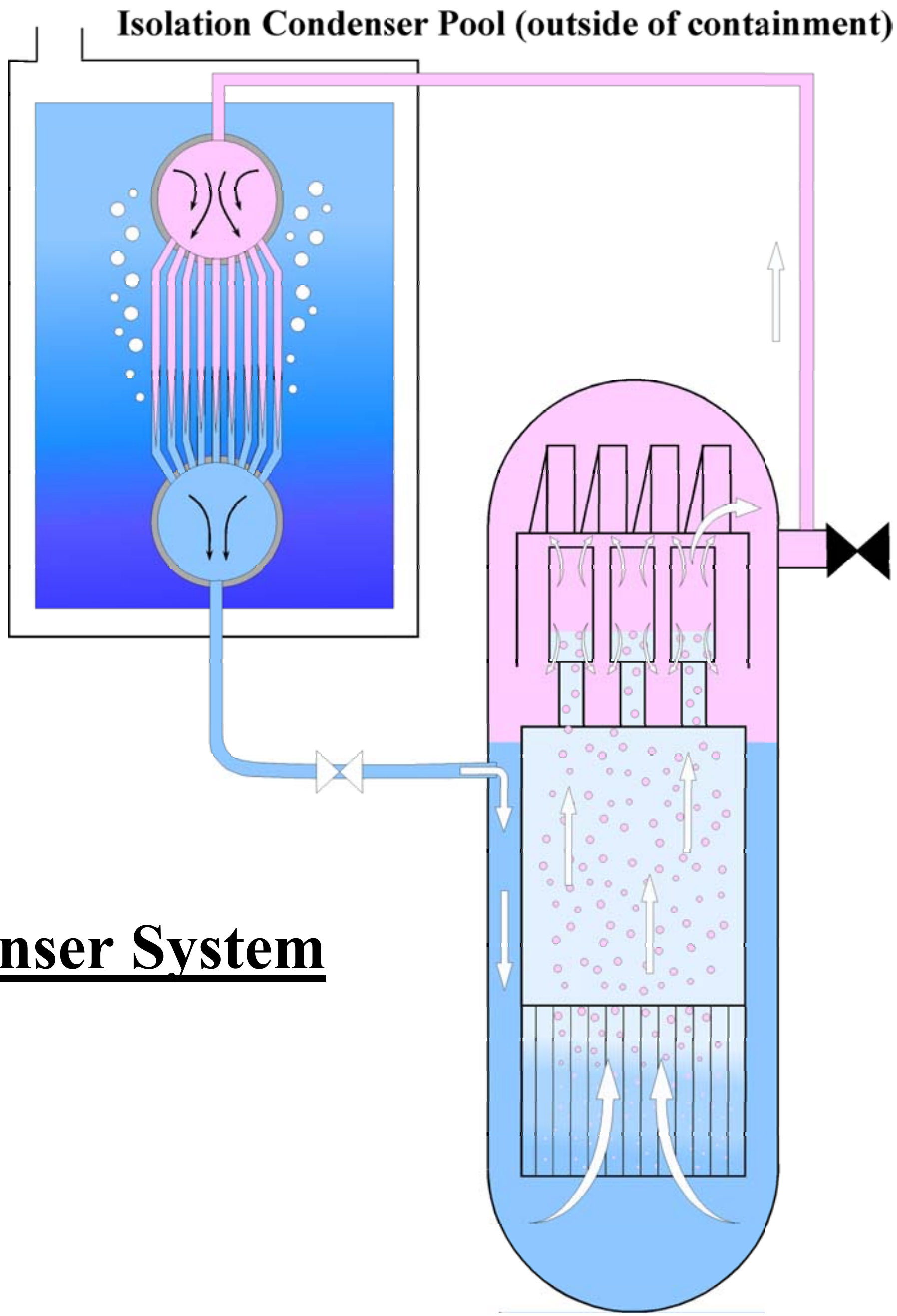
Decay Heat Removal Systems

- ***Remove Decay Heat From Vessel***
  - **Main Condenser**
  - **Normal shutdown cooling system**
  - **Isolation condensers**
  - **Remove vessel heat through relief valve opening**
- ***If Needed, Remove Heat From Containment***
  - **Suppression pool cooling (non-safety)**
  - **Passive containment cooling (PCC) Hx (safety-grade)**
    - Always available
    - Drywell/wetwell pressure difference drives the steam and non-condensable flow through the heat exchangers
    - Condensed steam returns to drywell/vessel, non-condensables collect in the wetwell airspace

Several Diverse Means of Decay Heat Removal

Decay Heat Removal from Vessel – How it Works

- ***Isolation Condenser - simple tube heat exchanger in a pool of water***
- ***Redundant, fail-safe valves open and water drains from tubes***
- ***Steam flows naturally to tubes and is condensed and condensate returns to vessel, energy transferred to pool outside containment***



Isolation Condenser System

Plant Features that Result in Optimum IC Response

- ***Large Reactor Vessel***
  - *slow pressure rate*
  - *no need for fast action*
  - *no loss of water inventory following isolation*
- ***Heat Sink Pool Outside Containment***
  - *no containment heat up*
  - *very easy to extend period of cooling*

Isolation condenser is a proven system that has been used in many operating plants

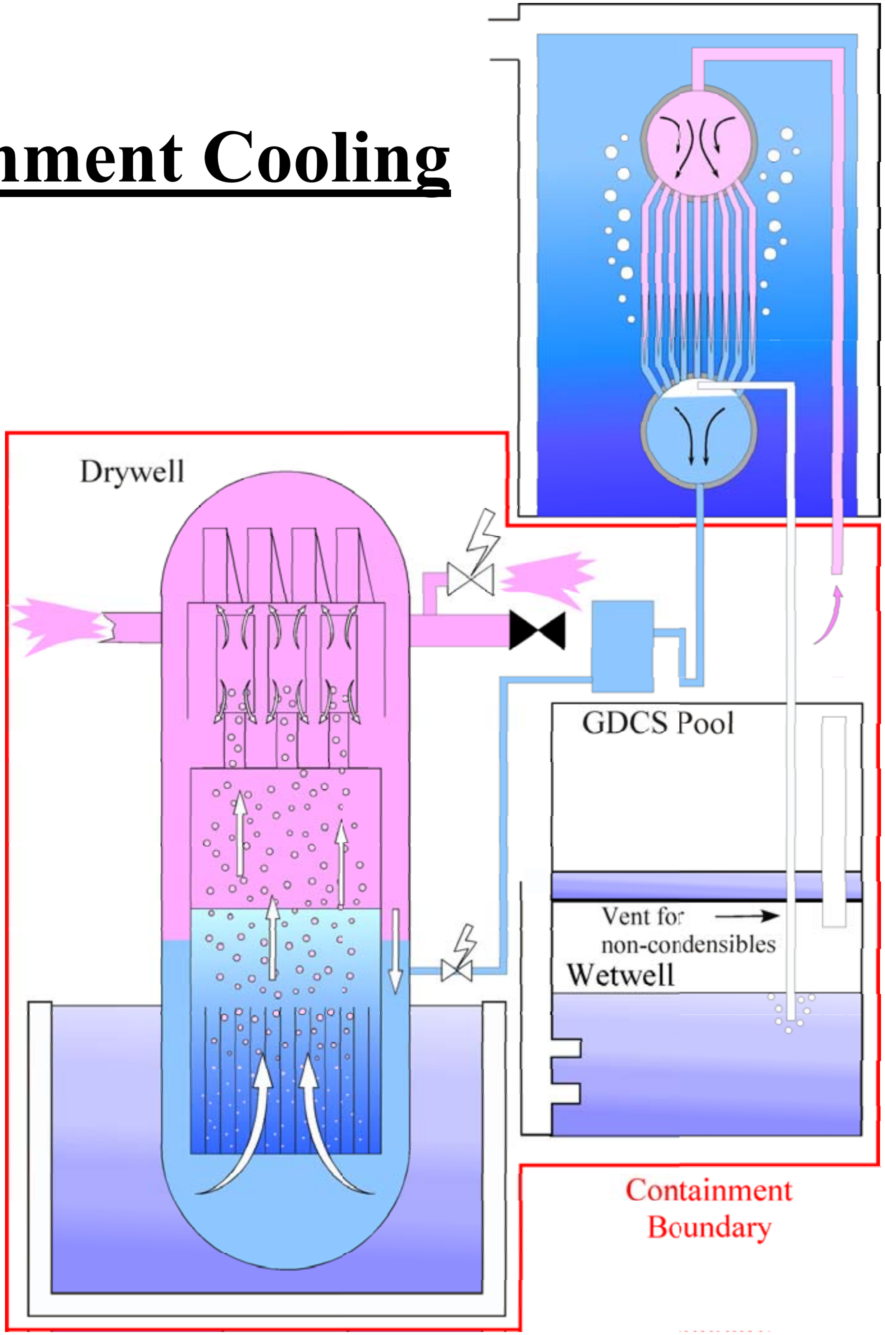
Decay Heat Removal from Containment - How it works

- ***Initially steam (blowdown energy) flows to large heat sink in containment (suppression pool) and through heat exchangers***
- ***Longer term (decay heat) steam flows to heat exchanger and heat is transferred outside containment***

  - Vertical tube heat exchangers in a pool of water

Concept is simple, reliable - extensive testing and analysis provide high confidence in the design margin

Passive Containment Cooling

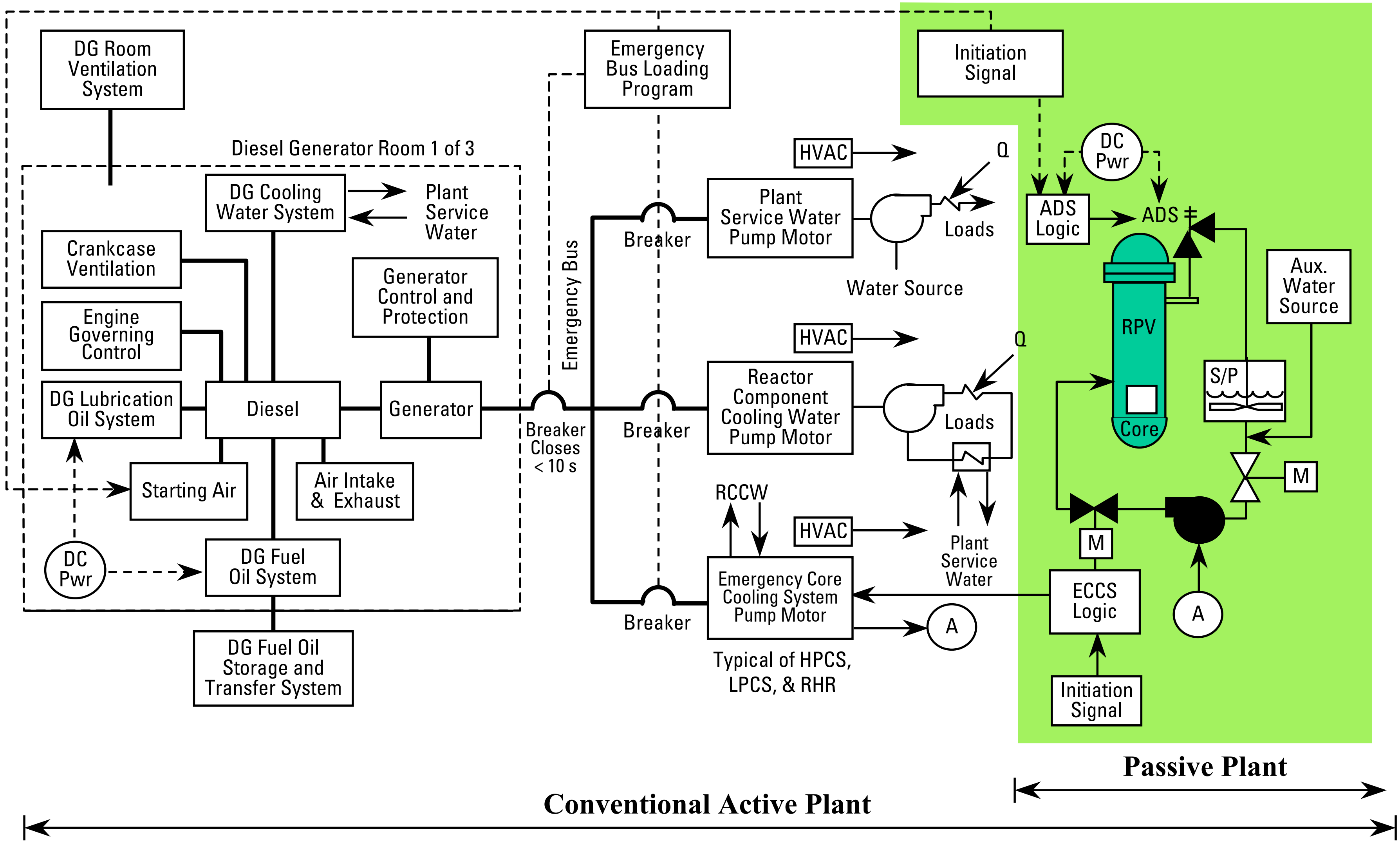


Plant Features Resulting in Optimum Containment Response

◆ *Pressure suppression system*	-	*no need for fast action*
	-	*allows heat exchanger to operate in forced flow conditions*
◆ *Compact heat exchangers*	-	*allow substantial margin in design without economic penalty*
◆ *Heat sink pool outside containment*	-	*very easy to extend period of cooling*

Containment heat exchangers are a major simplification
Modular design allows easy scale-up in power

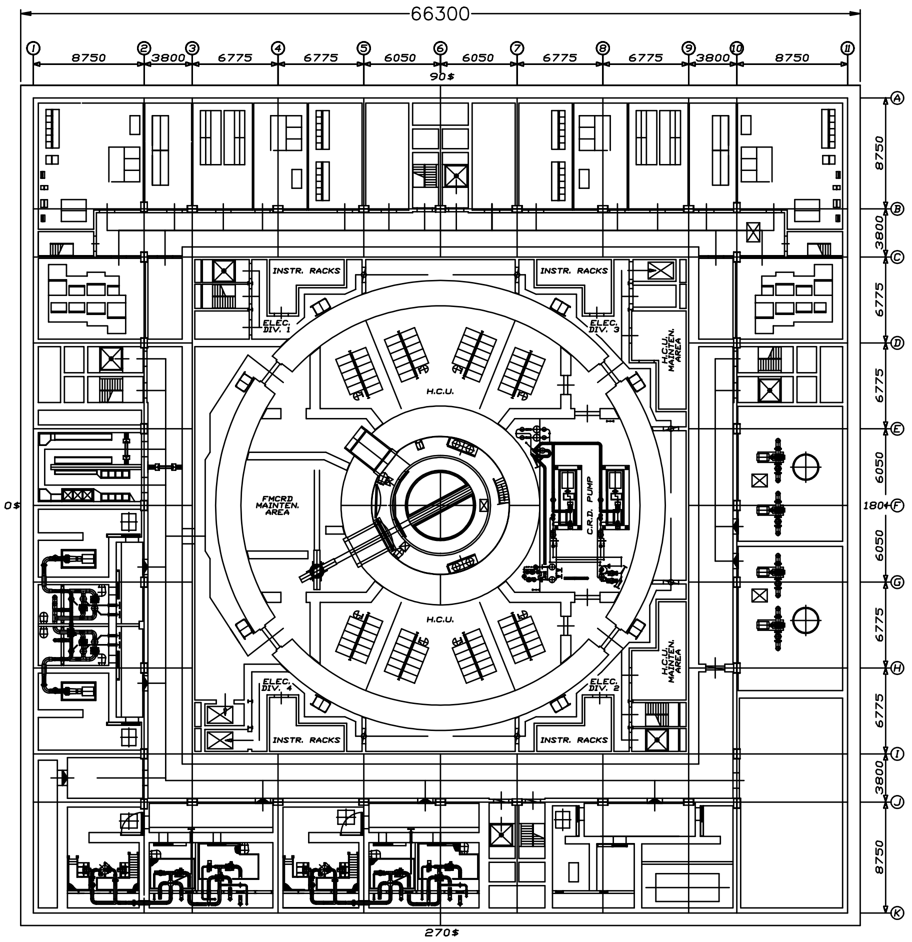
Comparison of Safety System - Passive vs. Active

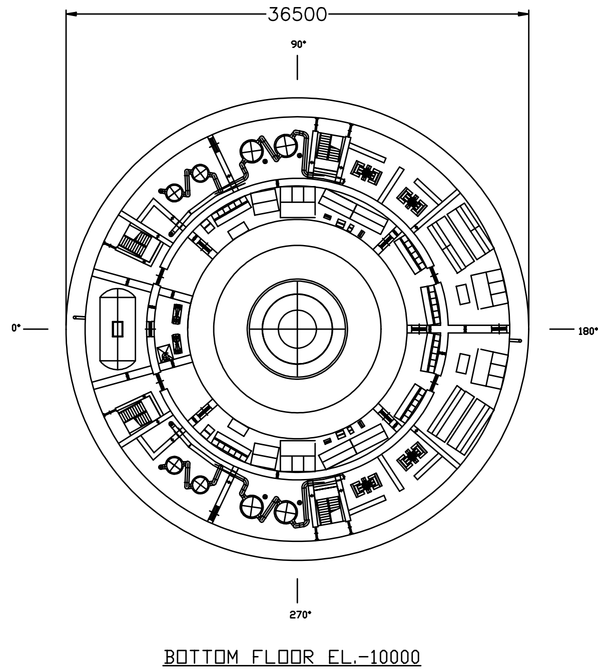


Passive systems are considerably simpler

SBWR (670 MWe)

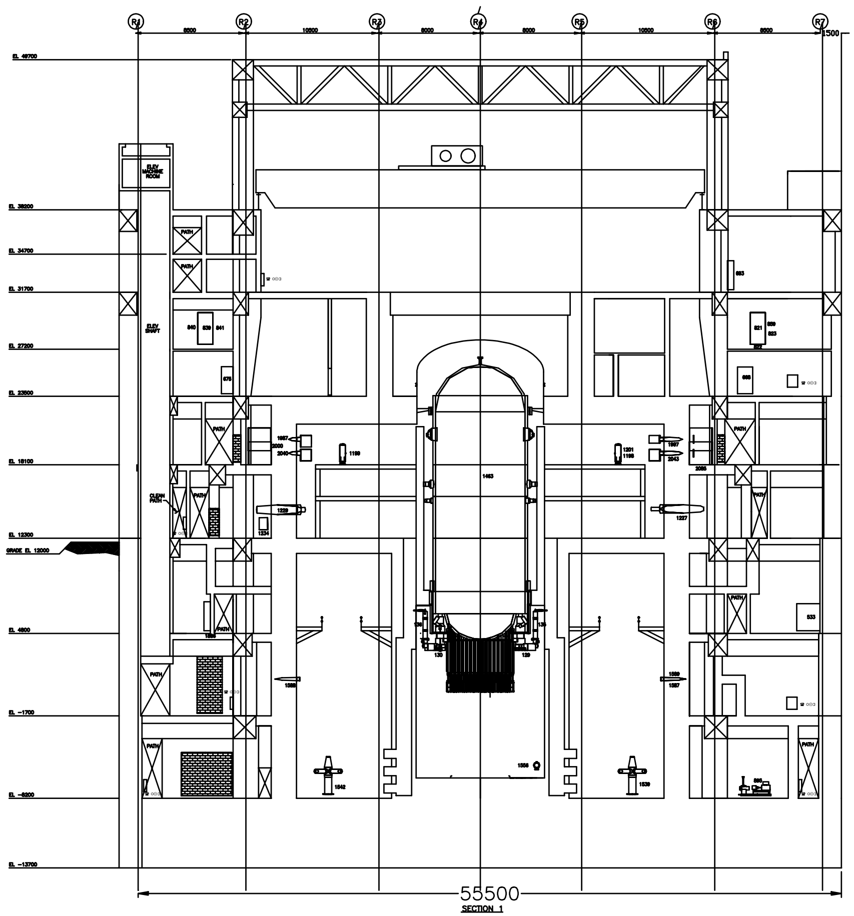
ESBWR (1380 MWe)



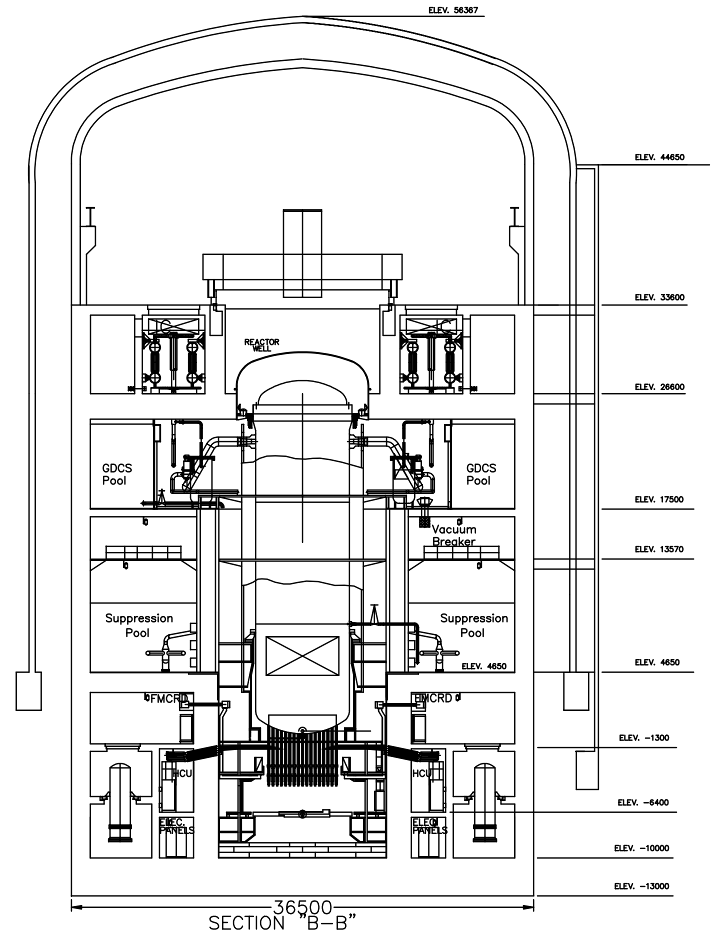


Significant Reduction in Systems & Buildings – scale up with innovations

ELEVATION COMPARISONS



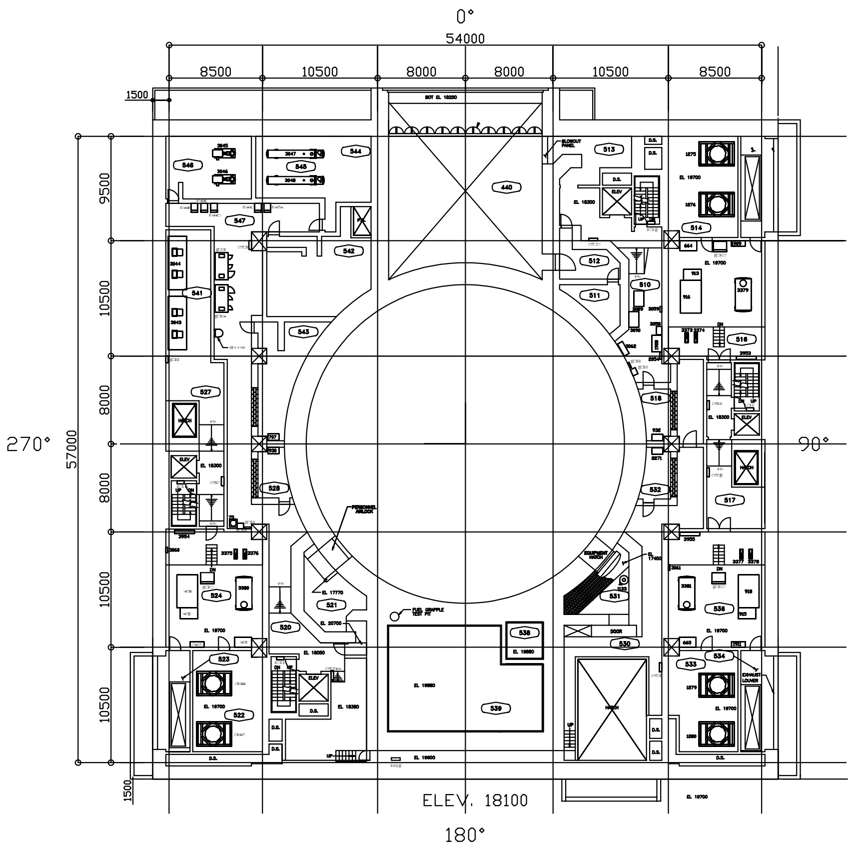
ABWR



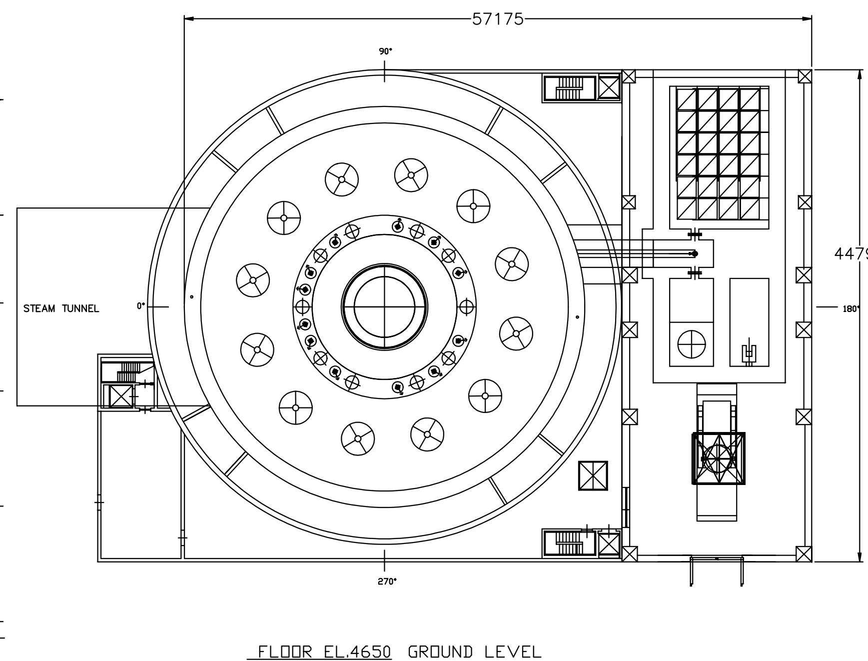
ESBWR

Significant Reduction in Systems & Buildings with passive systems

PLAN VIEW AT GRADE LEVEL



ABWR



ESBWR

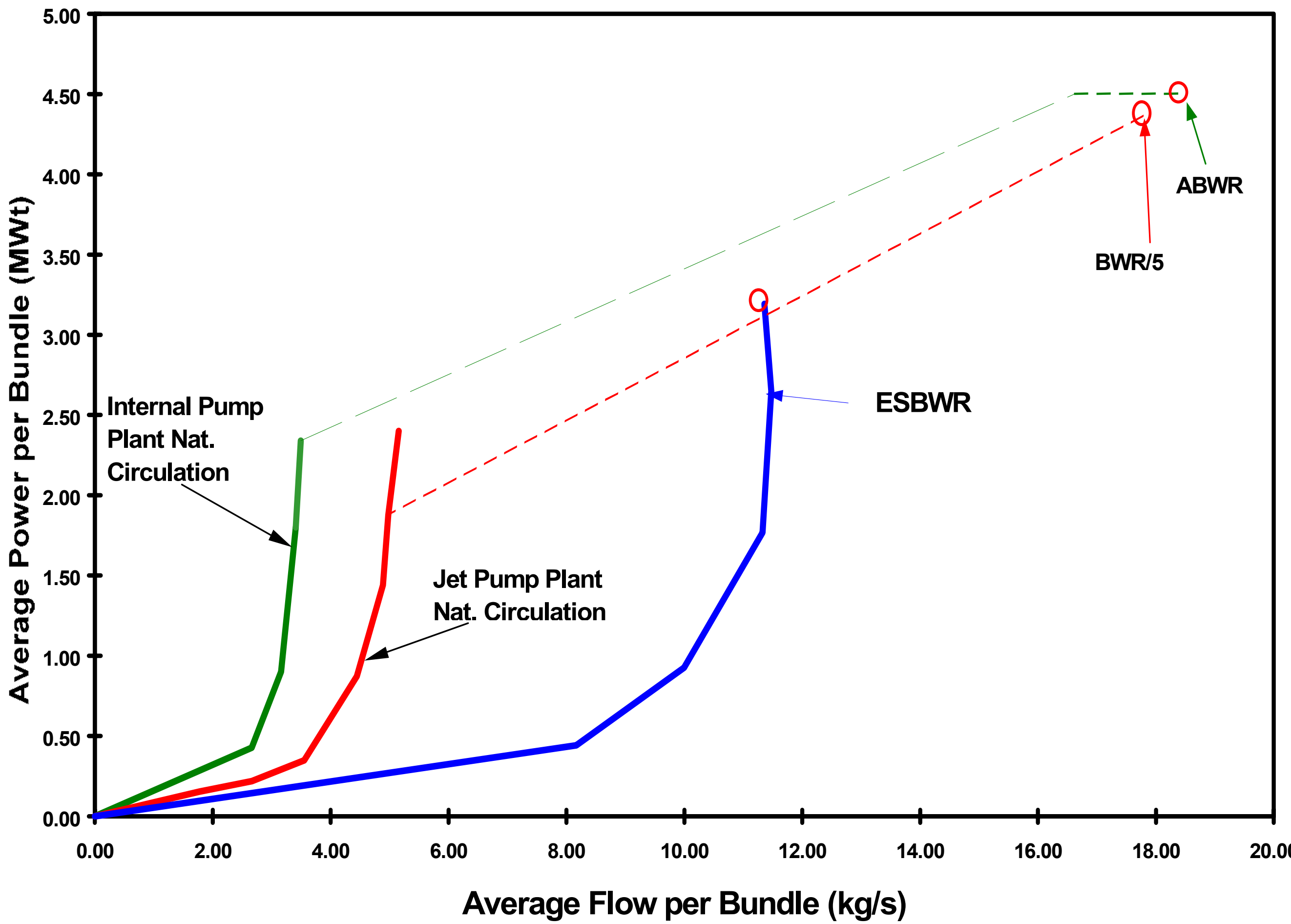
Significant Reduction in Systems & Buildings with passive systems

Outline

- History of ESBWR development
- Design summary
- Passive safety systems
- **Plant performance**
- Technology basis
- Pre-application plan
- Summary and Conclusion

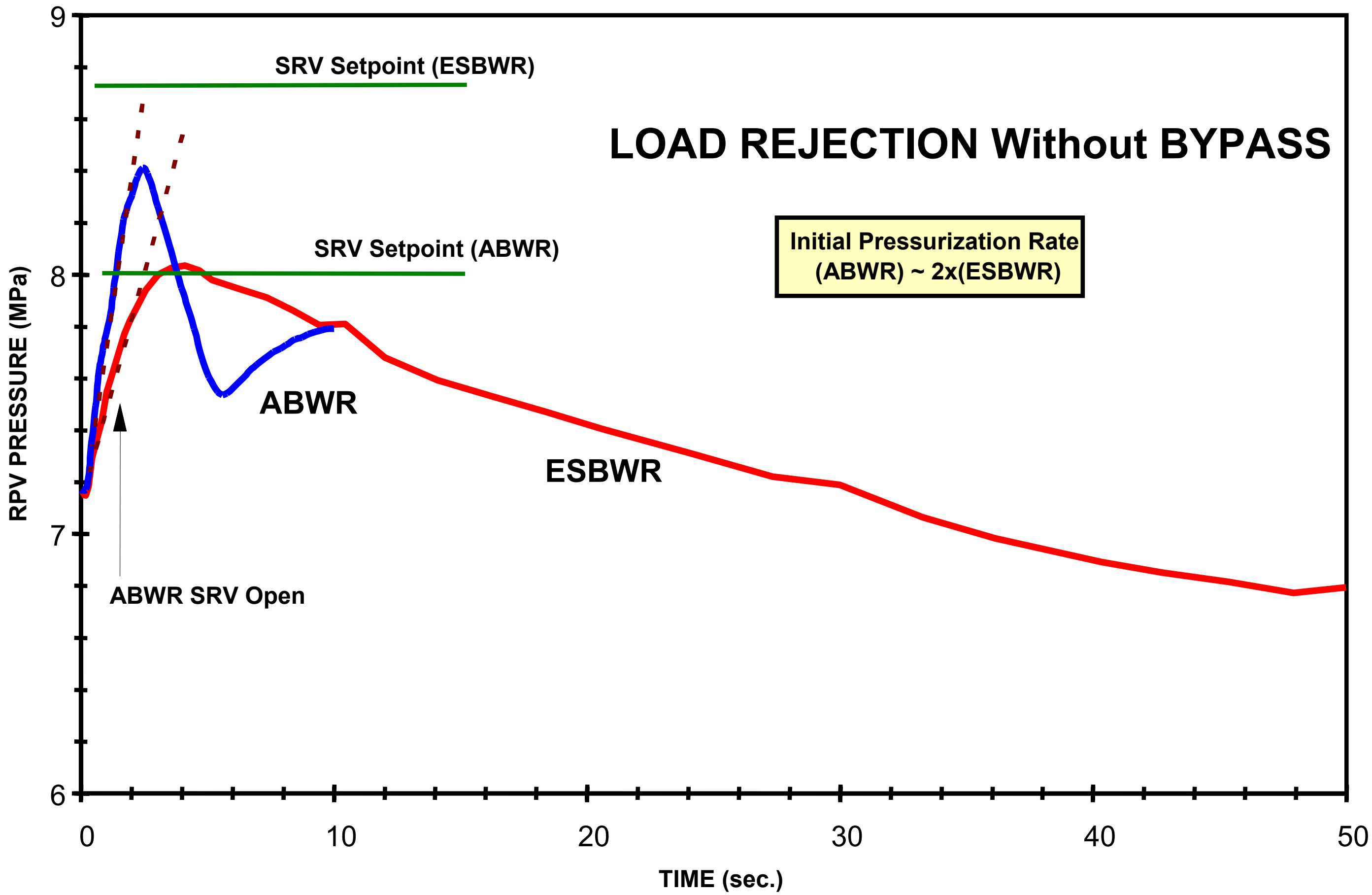
Plant performance margins enhanced by design changes

Comparison of Natural Circulation Flow for BWRs



ESBWR has large margin to unstable regions

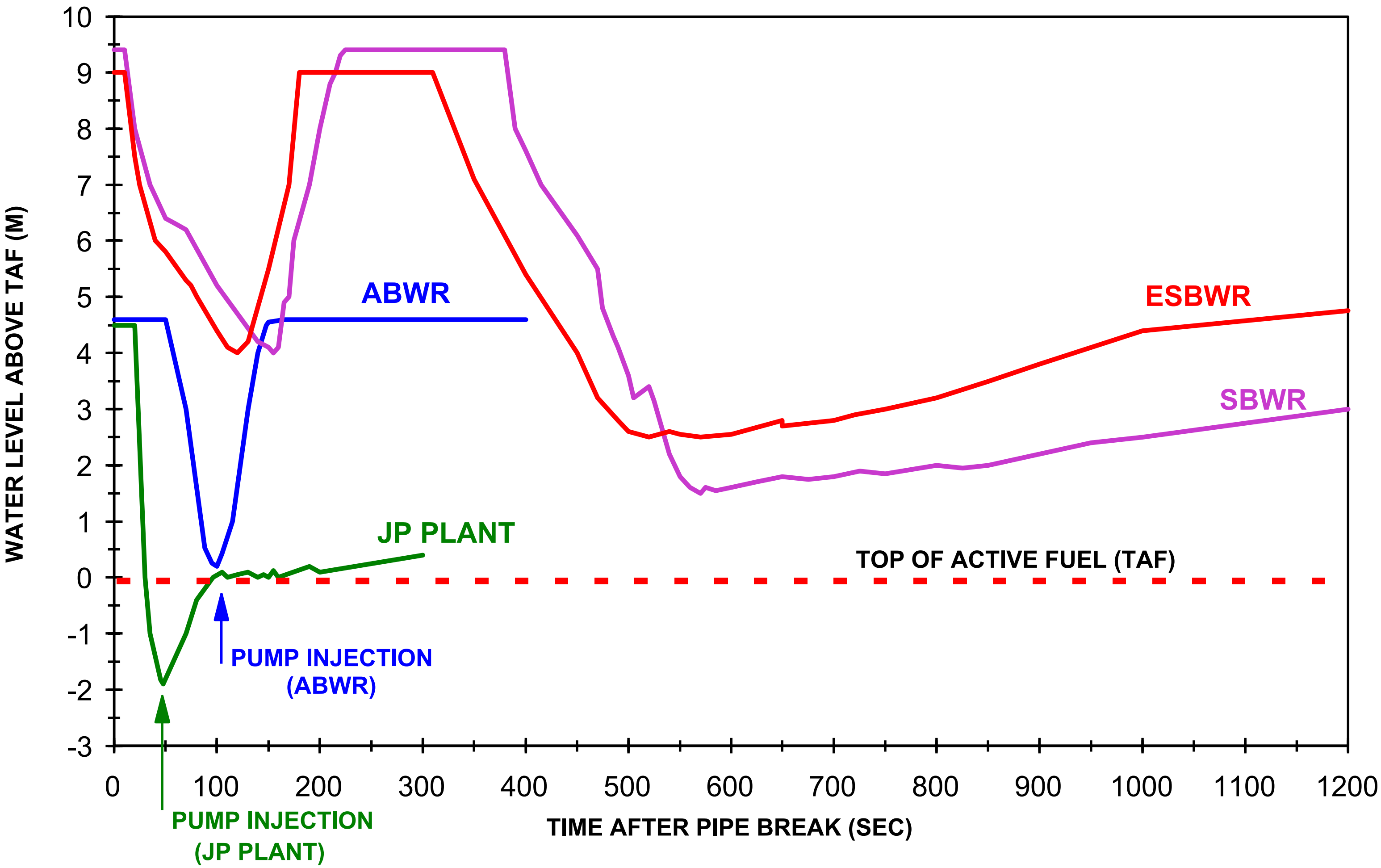
Reactor pressure response to isolation events



ESBWR has slower pressurization - no relief valves open

Water Level in Shroud Following a Typical Break

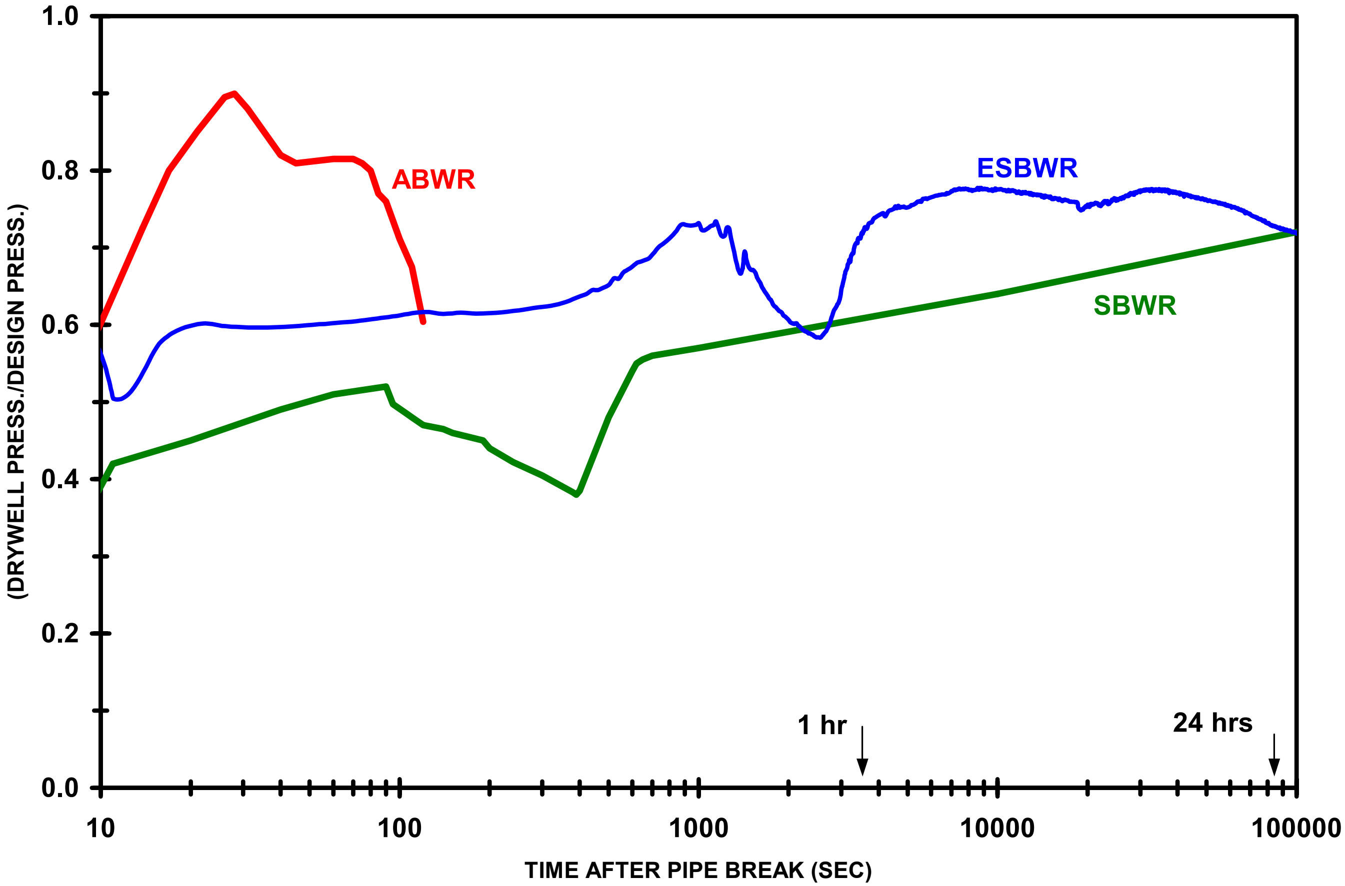
(values are intended to show typical trends for limiting breaks)



Large margins should facilitate regulatory review

Containment Pressure Following a Pipe Break

(values are intended to show typical trends for limiting breaks – ESBWR has lower design pressure than ABWR/SBWR)



Large margin to design pressure even without COP system

Outline

- *History of ESBWR development*
- *Design summary*
- *Passive safety systems*
- *Plant performance*
- ***Technology basis***
- *Pre-application plan*
- *Summary and Conclusion*

Extensive SBWR testing supplemented with additional ESBWR tests

Extensive Technology Program for Features New to SBWR

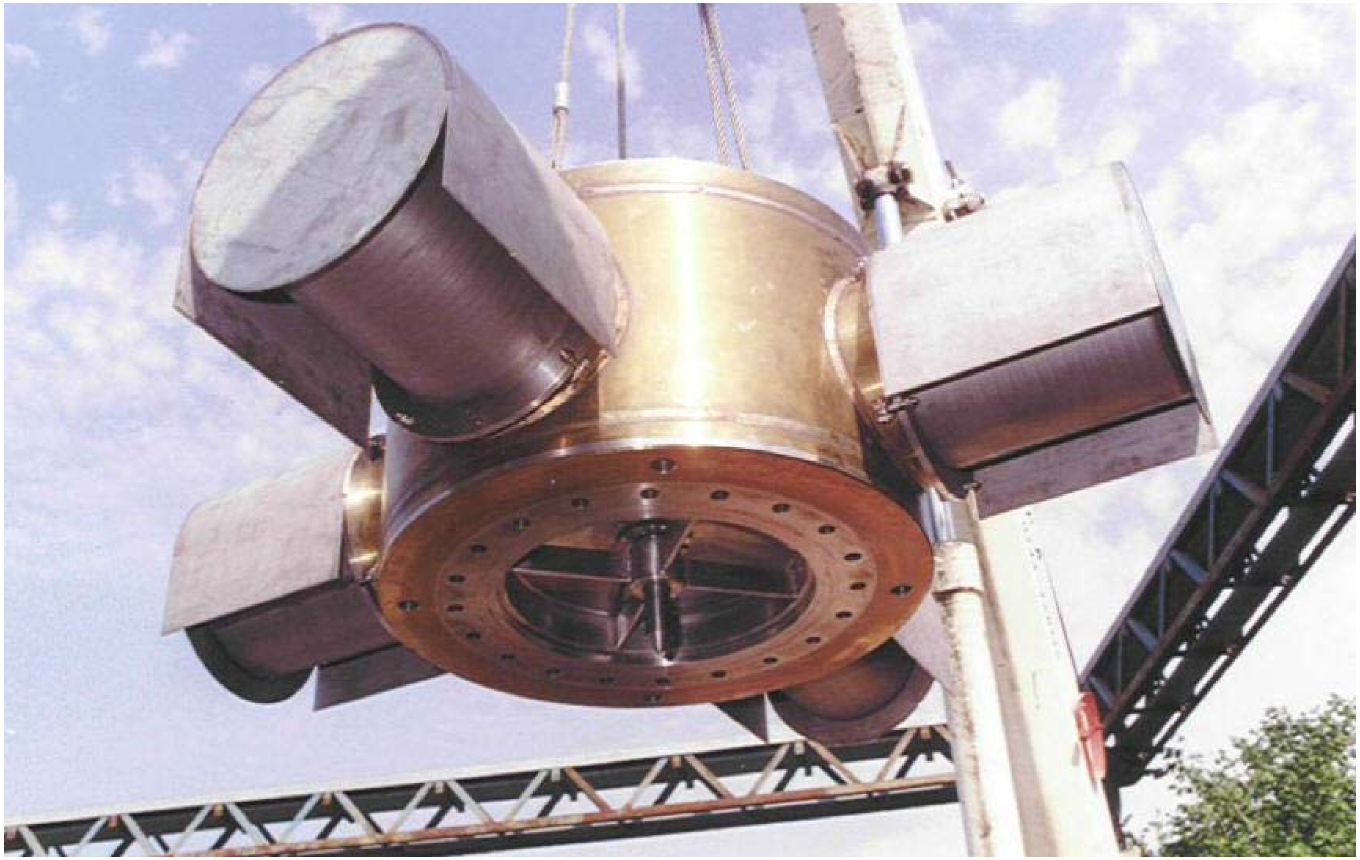
- ***Component tests***
  - Full scale components tests – DPV valves and vacuum breaker
  - Full scale isolation condensers & PCCS heat exchangers,
- ***Integral tests***
  - Integral tests at different scales – 1/400 to 1/25
  - System interaction tests
  - Large hydrogen releases
- ***Testing used to qualify computer codes***
- ***Extensive international cooperation***
- ***Extensive review and participation by NRC staff***
  - Test matrix
  - Running of actual tests

A Complete, Multi-year International Technology Program Supports the Design

Safety System (GIST) Test Facility and Depressurization Valve

Reactor Depressurization Valve in the Test Facility

Prototype Vacuum Breaker



Additional testing for ESBWR configuration

- ***Decay Heat Removal***

  8 Integrated system tests run in PANDA - TEPSS

  Pre- and post-test predictions

  - TRACG, TRAC-BF1, RELAP5 and MELCOR

- ***Natural circulation high pressure stability tests at CRIEPI***

Multi-year program extended the SBWR database to ESBWR

ESBWR Program Summary

- ***9 year ESBWR program***
  – Reduced Components and Systems - simplify
  – Reduced the Structures and Buildings - simplify
- ***9 year Technology Studies***
  – Large margins confirmed – increased over SBWR
  – Qualified codes for incremental changes for ESBWR
- ***Challenges for the Coming Years***
  – Can simple design, large margins and completed testing simplify the regulatory challenges?

Improved Performance and Economics
Completed Extensive Technology Program
SBWR/ABWR ease Regulatory Challenges for ESBWR

Outline

- History of ESBWR development
- Design summary
- Passive safety systems
- Plant performance
- Technology basis
- **Pre-application plan**
- Summary and Conclusion

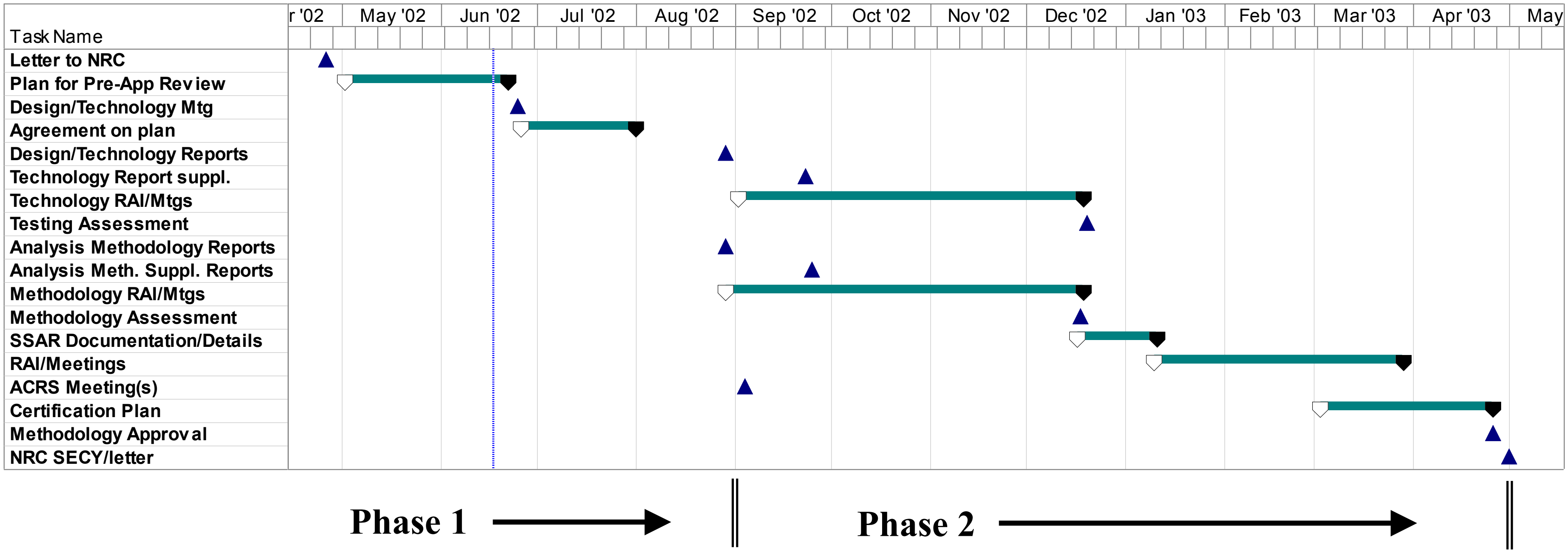
12 month plan to obtain cost and schedule for ESBWR certification

Pre-application review plan

- ***12 month plan to obtain cost and schedule for certification***
  - Complete plant description provided as reference – not for review
- ***3 specific issues to be addressed***
  - Adequacy of testing for passive safety systems
  - Approval of methodology for evaluating plant performance
  - Technical details needed in the SSAR
- ***Key dates***
  - Submittals for review – August 2002
    - Some supplements to be provided September 2002
  - Adequacy of testing– Dec 2002
  - Initial assessment on methodology – Dec 2002
  - Completion of pre-application review – April 2003

Based on timely submittals and responses to RAI's
Address NRC issues and concerns from SBWR review

ESBWR Pre-application Schedule



The above DRAFT plan shows the key steps to achieve the following:

1. Phase 1 agreement by July 2002 to define the issues to be resolved during the pre-application review. This agreement to include NRC cost and schedule for the Phase 2 activities.
2. Phase 2 activities are expected to cover the following 3 issues:
   - 2.1 Assessment of the technology basis for the passive safety systems
   - 2.2 Approval of the Analysis Methodology for analyzing plant transient, LOCA, containment response
   - 2.3 Definition/agreement on SSAR and certification document details
   - 2.4 Cost and schedule for certification
3. Phase 2 activities are scheduled based on getting early evaluation of 2.1 and 2.2 and given that the design has large margins to LOCA and containment limits.
4. The DRAFT schedule is based on timely GE submittals – especially the ones defining the start of Phase 2 in August and timely responses to RAI's.

Basis for schedule

- ***Adequacy of testing issue***
  - **NRC completed review of SBWR testing and analysis program**
    - Found to be adequate – RAI's covered issues that did not affect conclusion
  - **Additional ESBWR testing done for specific configuration changes**
  - **Scaling report covers the test programs**
    - Found to be adequate – RAI's were addressed
- ***Approval of analysis methodology – TRACG***
  - **Model description and qualification report completed for operating plants**
    - Supplement extending qualification to passive safety systems (SBWR)
    - Supplement covering ESBWR specific tests
  - **Application methodology**
    - Transients - same as operating plants
    - LOCA and containment – bounding approach
  - **Large margins in plant performance based on design features**
  - **Plant bounding response can be calculated/analyzed easily**

Basis for schedule (cont.)

- ***Design certification submittal details***
  - **Rely on previous reviews regarding details/approach**

Extensive SBWR submittals and reviews, new test data and reports, coupled with design changes to add margin, provide a solid basis

ESBWR Design/Technology based on SBWR and ABWR

Summary and Conclusions

- ***Passive safety systems have simplified the plant design***
  - Plant evaluations are simpler and rely on less complex analyses
  - Substantial margins exist in the design
  - Defense in depth systems provide back-up
- ***ESBWR is an optimized design***
  - Simplified the design
  - Improved operation and maintenance
  - Enhanced the plant economics
- ***Next significant step is certification***
  - Design Certification schedule and resources are a key issue

Enhanced performance and economics and a solid technology basis provide confidence in the design