NUCLEAR ENERGY RENAISSANCE:
ADDRESSING THE CHALLENGES OF CLIMATE CHANGE AND SUSTAINABILITY
NCSR DEMOKRITOS
Athens

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NEW POWER REACTOR DESIGNS

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SUMMARY OF PRESENTATION

- Introduction
- Principal Reactor Types
- Four Generations of Reactor Design
- The New Reactors
- Main Features of the New Reactors
- Focus on LWRs
- Future Prospects
- Conclusions

MAIN REACTOR TYPES

Two Principal Classes:

- **LIGHT WATER REACTORS**
  - Boiling Water Reactors (BWRs)
  - Pressurized Water Reactors (PWRs)
- **NON-LWR REACTORS**
  - Heavy Water Reactors (CANDU)
  - Gas-Cooled Reactors
  - Liquid Metal Fast Breeder Reactors

FOUR GENERATIONS OF REACTOR DESIGN

- **1950 – 1965 GEN I** –Dresden, Shippingport, Fermi
- **1970 - 1990 GEN II** –LWR, BWR, PWR, CANDU, VVER, RBMK
- **1995 – 2010 GEN III** -ABWR, SYSTEM 80+, AP600,
- **2010 – 2030 GEN III+** -Evolutionary Design, Improved Safety and Economics: AP1000, EPR, ESBWR, APR1400
- **2030 - ?? GEN IV**– Enhanced Safety, Economics, Proliferation-Resistant

4 GENERATIONS OF REACTORS

GEN I

- Original LWR Designs (’50s–’60s)
  - Several Reactors Built, most one-of-a-kind
  - Examples of GEN I Designs:

    BWR: Quad Cities-1 and -2; Dresden; Tarapur-1 and-2; Fukushima-1; Garigliano

    PWR: HB Robinson; Palisades; Early EDF Designs;

4 GENERATIONS OF REACTORS

GEN II

- Several Types Developed From GEN I
- Major Improvements Over GEN I But Not Revolutionary; Some New Technologies
- GEN I & II Reactors Individually Designed
- Based on Same Design Principles and Expertise From Conventional Designs
- Line Between Gen I and II Hard to Discern
- Most Completed in the 70s and 80s

4 GENERATIONS OF REACTORS
TYPICAL GEN II REACTORS

BWR: Oskarshamn-2; La Salle; Fuku-2; Tokai-2, Leibstatd

PWR: Seabrook; Diablo Canyon; North Anna; Ringhals-4; Tsuruga-2

PHWR: Pickering, Rajasthan, Wolsong

AGR: Hartlepool

Based on Proven and Mature Technology, LWRs, and PHWRs, Became Dominant Commercial Power Reactors

NEW REACTORS
GEN III REACTORS

- GEN II + Evolutionary Improvements Developed During Lifetime of GEN II Reactors
- Main Features of GEN III:
  - Improved Fuel Technology
  - Passive Safety Systems
  - Standardized Design

NEW REACTORS
GEN III REACTORS

- Safety Conditions Can Be Maintained w/o Active Control Components– (Automation)

- **GEN III** Reactors:
  - **ABWR –** Advanced BWR (GE)
  - **System 80+** (C-E/ABB/Westinghouse)
  - **AP600** – Advanced Passive (Westinghouse)

NEW REACTORS
GENERATION III+

- Extension of GEN III Concept That Includes Advanced Passive Safety Features

- **GEN III +**
  - **AP1000** -Advanced Passive (Westinghouse)
  - **ESBWR -**Economic Simplified BWR (GE)
  - **EPR -**Evolutionary Power Reactor (AREVA-EDF)
  - **ACR** -Advanced CANDU Reactor (AECL)
  - **KNGR –**Korean Next Generation Reactor (Hanjung/C-E)

NEW REACTORS
GEN III and III+

BWR	PWR	NON-LWR
ABWR	AP600	ACR
SBWR	AP1000	PBMR
ESBWR	System 80+	PBMR
	EPR	LMFBR*

* Never Built

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GEN-III+ U.S. Certification Status

- **AP-1000** (Advanced Passive PWR), Westinghouse 1000 MWe (Cert.)
- **ESBWRR** (Economic Simplified BWR), General Electric, 1550 MWe (Being Cert.)
- **EPR** (Evolutionary Power Reactor), Areva/Framat. ANP, 1600 MWe (Pre-Cert.)
- **ACR-1000** AECL, (Advanced CANDU Reactor), 1000 MWe; Application Withdrawn By AECL
- **APR-1400** (KNGR) Based on System 80+ (Westinghouse/Mitsubishi) (Certification Handled By The Koreans)

NEW REACTORS
GENERATION IV

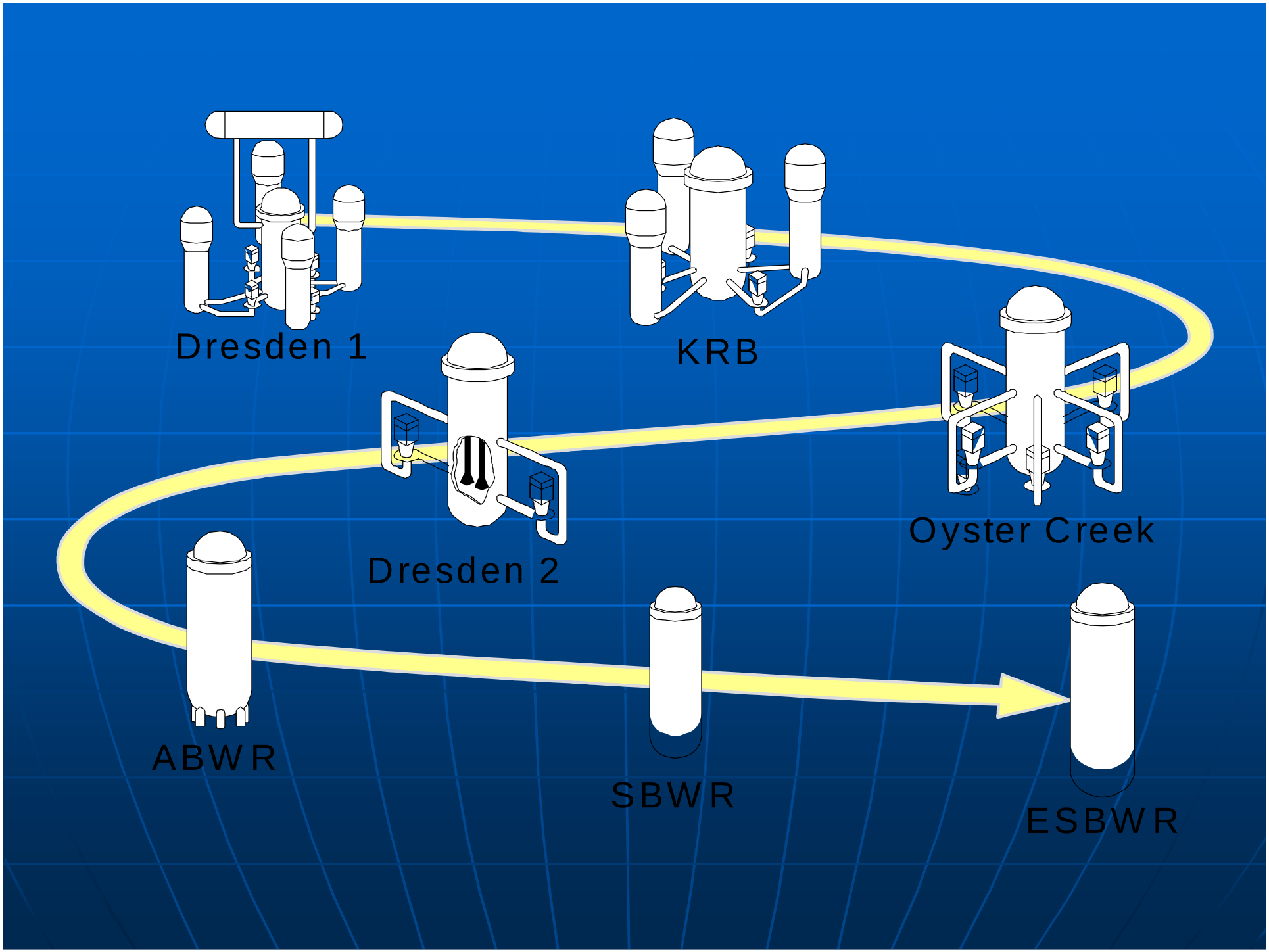
- GEN II And III Designs Provide Secure , Low Cost Energy Supply
- Further Advances In Reactor Design Will Broaden Opportunities For The Use Of Nuclear Energy
- U.S. Dept. Of Energy Has Engaged Governments, Industry and Research Community World Wide In Wide Ranging Discussions on the Development of the Next Generation of Nuclear Energy Systems Known as **GEN IV Design.**

NEW REACTORS
GENERAL CHARACTERISTICS

- Except for LMFBR, All Are Thermal Reactors
- Power Level: ~3500 MWth (~34% Efficiency)
- LWRs Use Light Water as Moderator and Coolant
- Fuel Is Low-Enrichment U^{235} (<5% U^{235})
- Some New Designs Contain **M**ixed UO_2 and Pu **Ox**ide (MOX Fuel)
- 18-24-Month Cycle Before Refueling
- New Reactors Attain High Burnups

THE NEW BWRs

- **EVOLUTION OF THE BWR**


Dresden 1
KRB
Dresden 2
Oyster Creek
ABWR
SBWR
ESBWR

THE NEW BWRs

- **ABWR** – Advanced BWR, GEN II, 1350 MWe
  - Certified 1997
  - 4 ABWRs in Operation in Japan
  - More Are Planned
  - 2 Units Under Construction in Taiwan
  - 2 Units Considered for South Texas

ESBWR-Economic Simplified BWR, GEN III+,1550 MWe

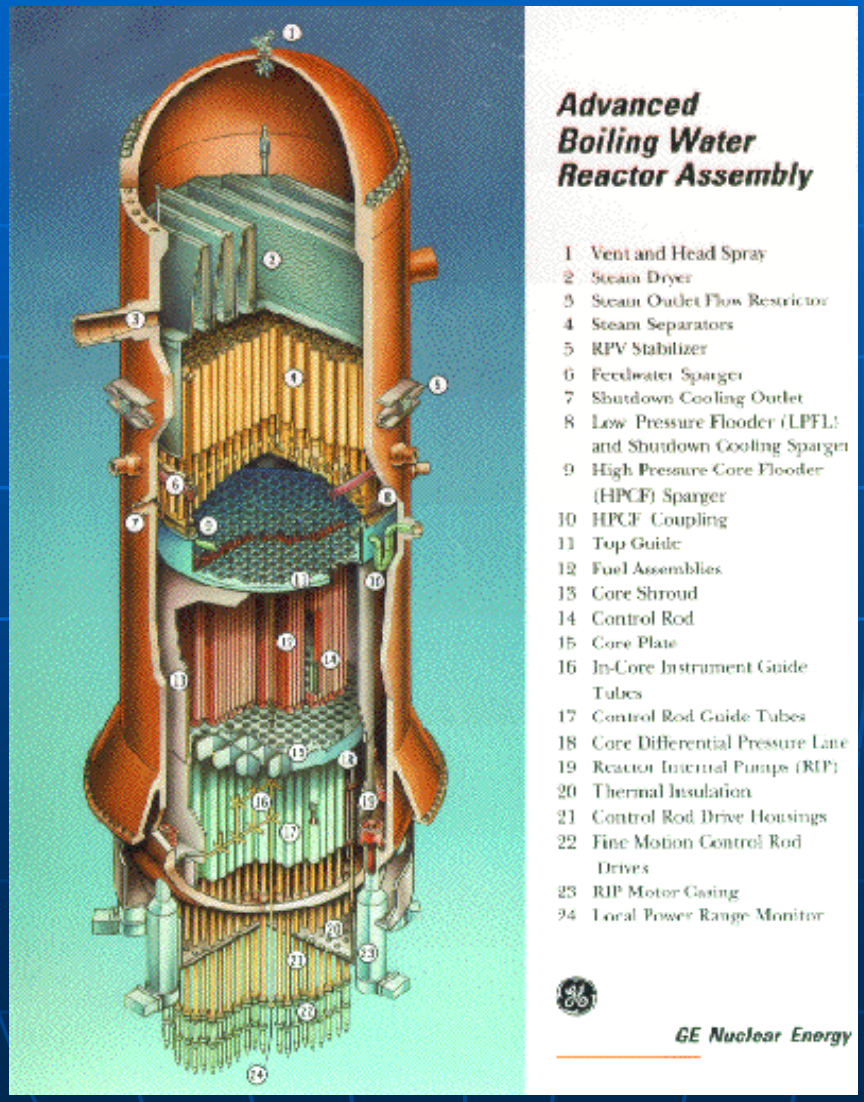
- Undergoing Certification
- Dominion, Entergy Interested

THE NEW BWRs

ABWR

- Certified in 1997; Power: ~1350 - 1460 MWe
- Improved Safety, Reliability, Operability, And Maintainability
- Demonstrated Reduction In Capital And In Operating Costs
- Design Based on Proven Advanced Reactor Technology And Performance Enhancements
- Optimized Modularization
- Shorter Construction Time of ~ 39 Months From First Concrete To First Fuel Load Proven In Japan Technology

THE NEW BWRs



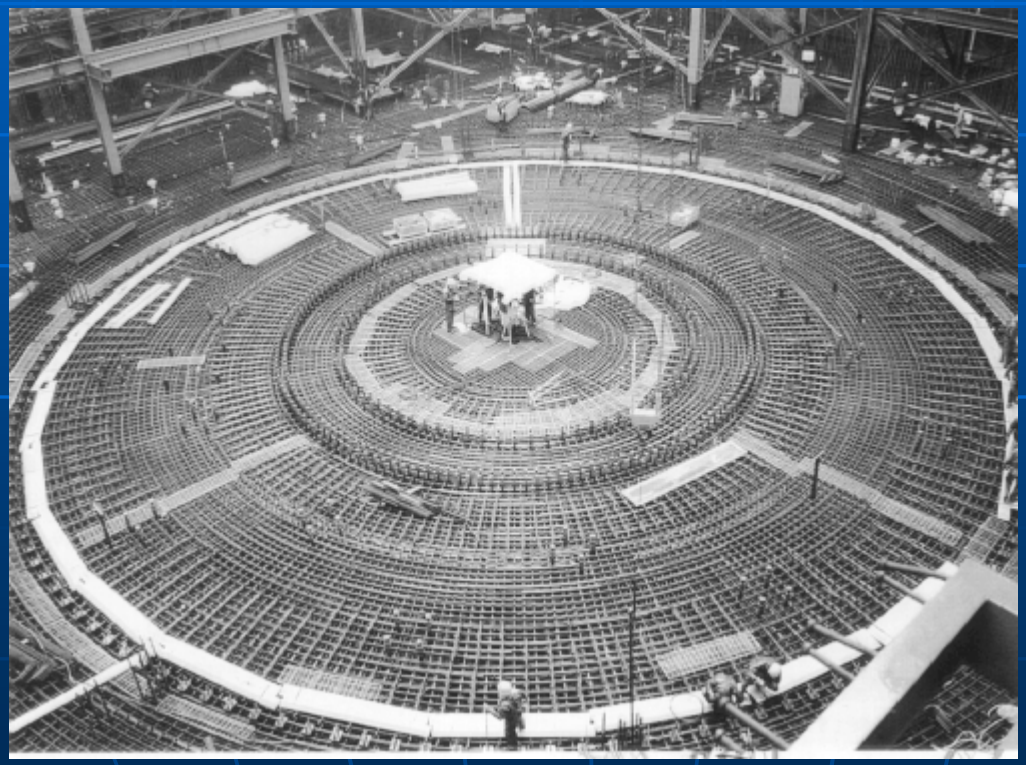
Advanced Boiling Water Reactor Assembly

1 Vent and Head Spray
2 Steam Dryer
3 Steam Outlet Flow Restrictor
4 Steam Separators
5 RPV Stabilizer
6 Feedwater Sparger
7 Shutdown Cooling Outlet
8 Low Pressure Flooder (LPFL) and Shutdown Cooling Sparger
9 High Pressure Core Flooder (HPCF) Sparger
10 HPCF Coupling
11 Top Guide
12 Fuel Assemblies
13 Core Shroud
14 Control Rod
15 Core Plate
16 In-Core Instrument Guide Tubes
17 Control Rod Guide Tubes
18 Core Differential Pressure Line
19 Reactor Internal Pumps (RIP)
20 Thermal Insulation
21 Control Rod Drive Housings
22 Fine Motion Control Rod Drives
23 RIP Motor Casing
24 Local Power Range Monitor

GE Nuclear Energy

THE NEW BWRs

- ABWR Under Construction in Japan



THE NEW BWRs

- ABWR Under Construction In Japan

THE NEW BWRs

- ABWR Under Construction In Japan

ABWR

ADVANCED BOILING WATER REACTOR

- 4 ABWRs Already Operating in Japan
- 2 Under Construction in Taiwan
- 2 Being Considerd for South Texas
- Low Cost of Building ABWRs in U.S. Has Attracted Potential Customers

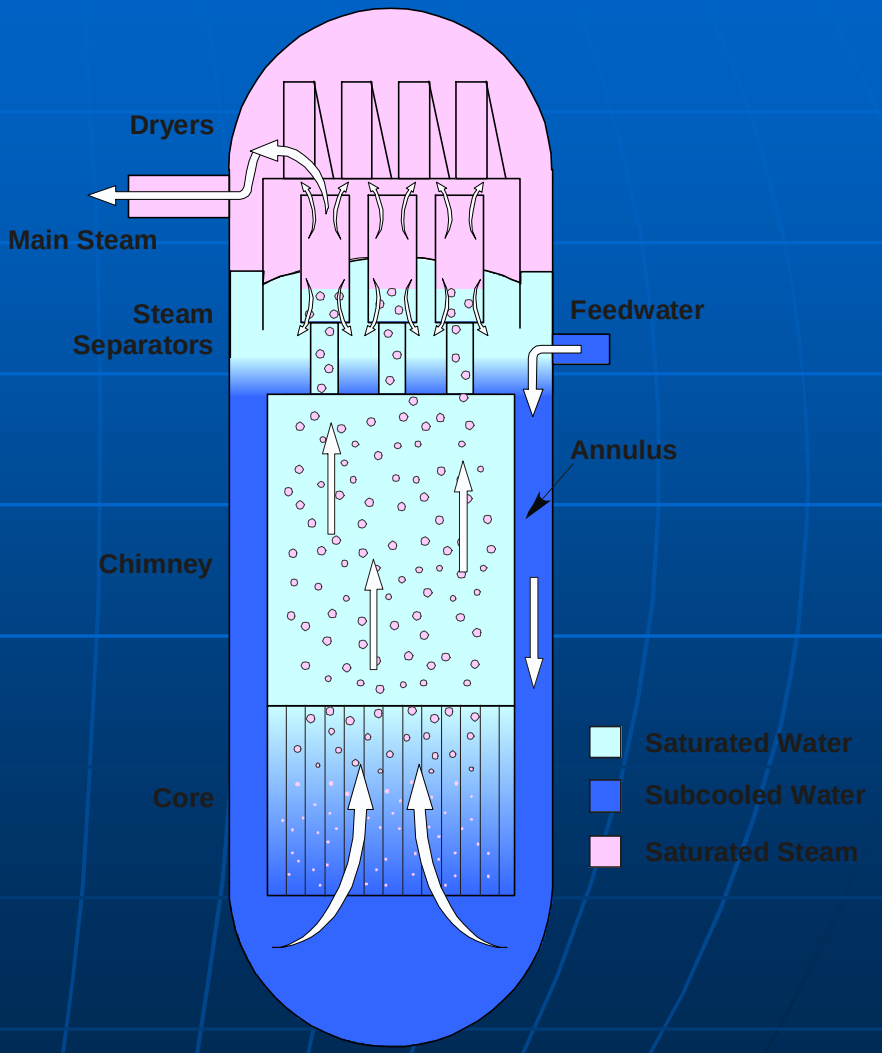
THE NEW BWRs

ESBWR Quick Facts

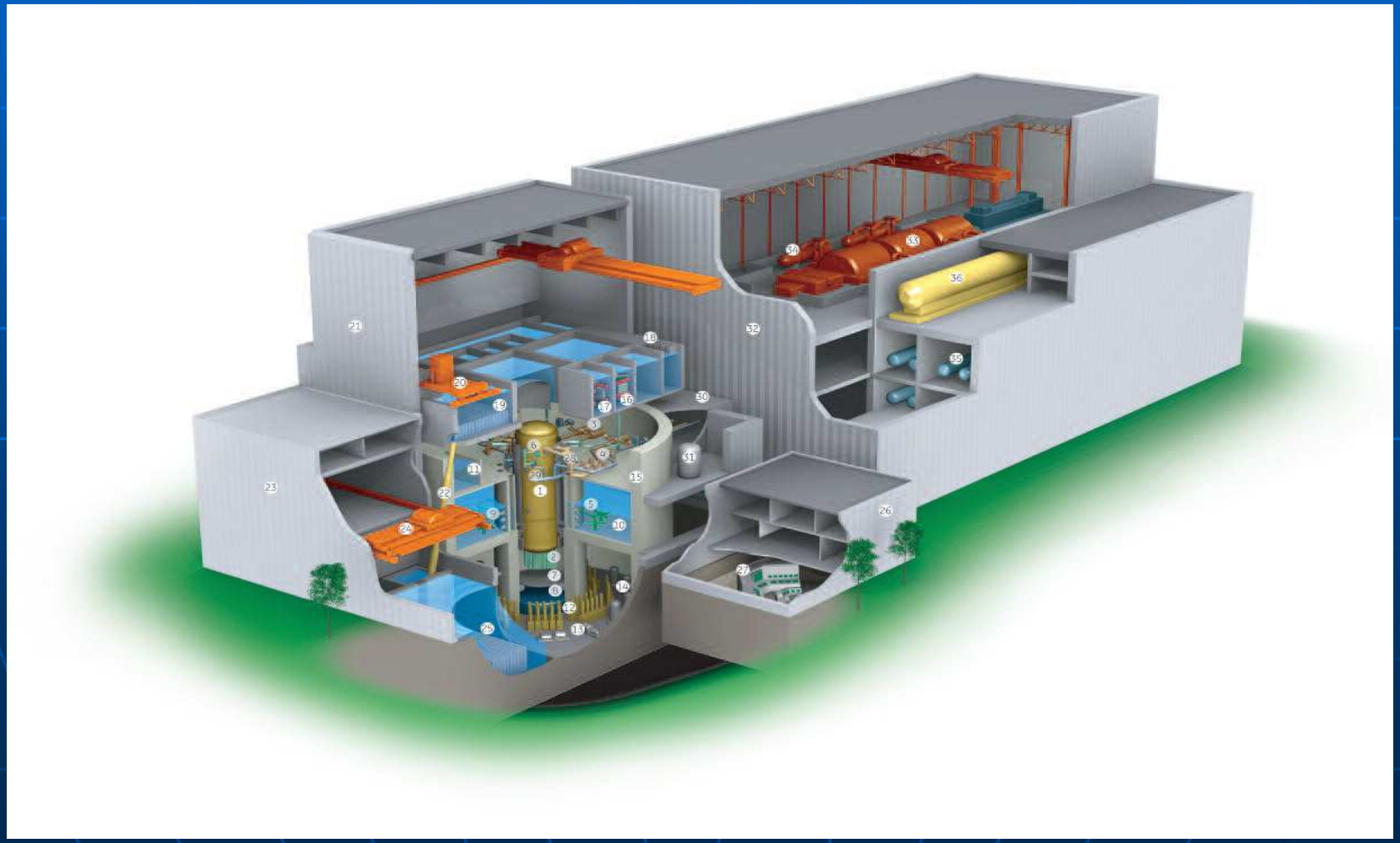
- Referenced Construction Schedule Of 42 Months
- One ESBWR, Replacing The Same Amount Of Electricity Generated In The U.S. Through Traditional Sources, Would Reduce Greenhouse Gas Emissions By An Amount Equivalent To Taking 1.5 Million Cars Off The Road

ESBWR

- Natural circulation in ESBWR is designed with an unrestricted downcomer, enhanced through optimization on the chimney height, active core length, and separator configurations.



ESBWR PLANT LAYOUT



THE NEW PWRs

- **AP600,** Westinghouse, 600 MWe,
  Certified 1998
  - Simplified Design; Costs Less To Build
- **AP1000,** Westinghouse, 1000 MWe
  An Extension of AP600
- **System 80+** Combustion Eng. +ABB
  Design, GEN III, > 1300 MWe, (Now Incorporated Into Westinghouse Design)
  Certified 1999
- **APR 1400,** Advanced PWR Design,
  Evolved from System 80+, GEN

THE NEW PWRs (Cont.)

- **EPR,** Evolutionary Pressurized Water Reactor, AREVA NP, GEN III+, 1600 MWe, Certification Targeted for 2009
  - Conventional PWR Design, but Simplified and with Enhanced Safety
  - Potential Future Sites: France, China, U.S.A. (UniStar Nuclear)

THE NEW PWR

AP1000


Westinghouse

THE NEW PWRs

AP1000

Advanced **P**assive **1000**

- Based on proven technology of Classical Westinghouse PWR plant and on AP600
- Simplified Plant Design
- Passive Safety Systems
- Reactor Power 3400 MWth
- Fuel Enriched to $4.95% UO_2
- Less Expensive to Build and Operate
- Accelerated Construction: ~36 Months
- NRC Certified in 2002

THE NEW PWRs

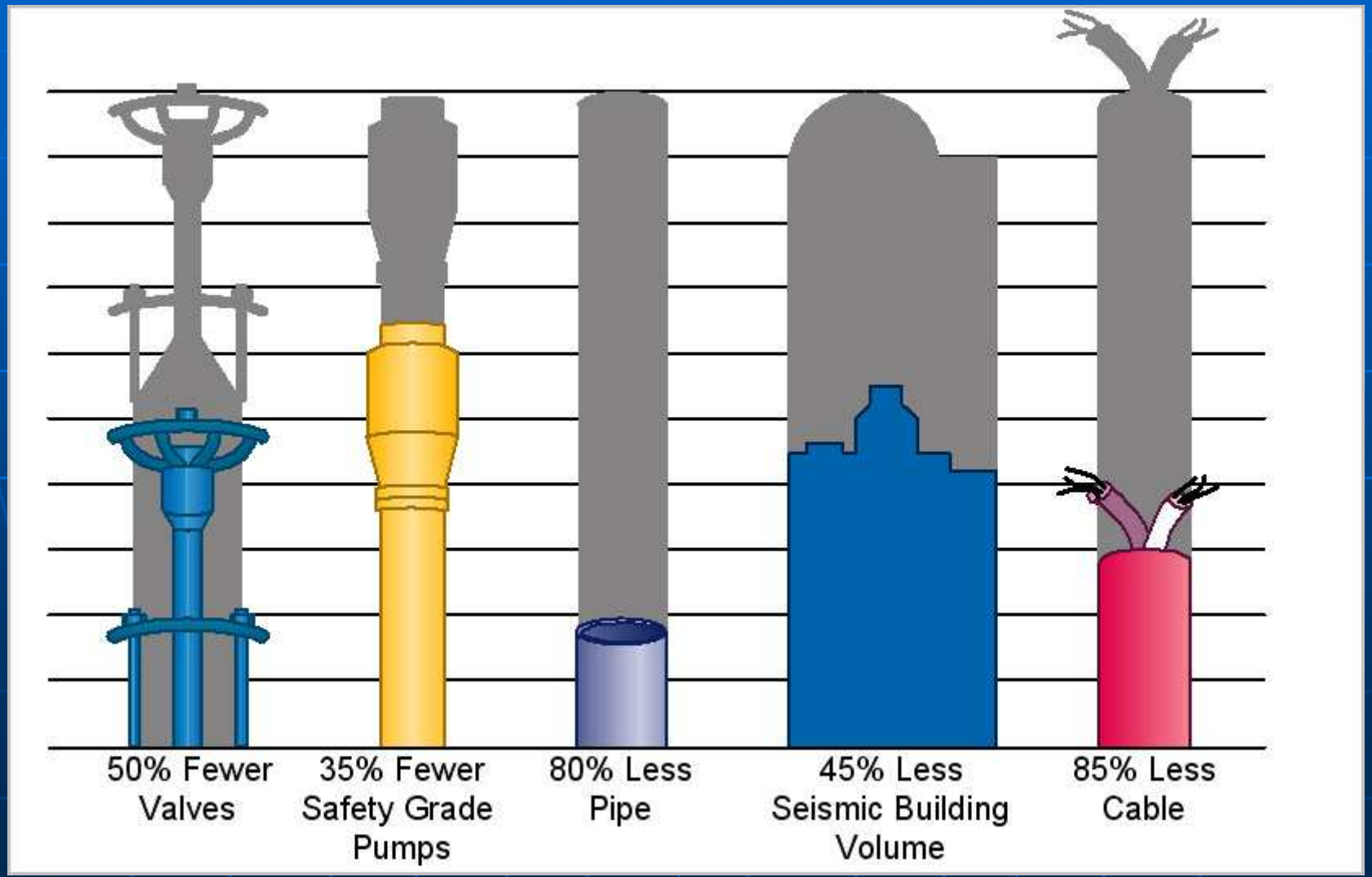
- **AP1000** (Cont)

- Operating Cycle Length: 18 Months
- 43% Fuel Replaced at Refueling
- Modular Construction- 50 Small, 250 Large Modules
- 36 Months – Site Construction
- **W** Estimates ~60 Months to Utility Operation
- Approx. Cost: $1,000 - $1,100 Per 1,000 KWe

THE NEW PWRs
AP1000 -SAFETY ASPECTS

- Meets NRC Safety Criteria With Large Margins
- Multiple Levels of Defense for Accident Mitigation
- In the Event of a DB Accident, Plant is Designed to Shutdown Without Operator Action.

THE NEW PWRs
(AP1000)



THE NEW REACTORS

NON-LWR REACTORS

- **ACR,** Advanced CANDU Reactor, AECL,
  700-1200 MWe
  - Application Withdrawn By Usnrc
  - Evolved from CANDU line of PHWRs
  - Unlike Early CANDUs, ACR Uses D_2O Moderator and H_2O Coolant
  - In-Service Refueling
  - Potential Site: Ontario, Canada,

THE NEW REACTORS

NON-LWR NEW REACTORS

- **PBMR**, Pebble Bed Modular Reactor, Westinghouse, 165 MWe
  - High Temperature Gas-cooled Reactor
  - PBMR Supported By Eskom For South Africa
  - Pre-certification Status With USNRC
  - Uses He As Coolant
  - Prototype Variations Operate In Japan, China
  - Design Calls For Higher Enrichments Than LWRs

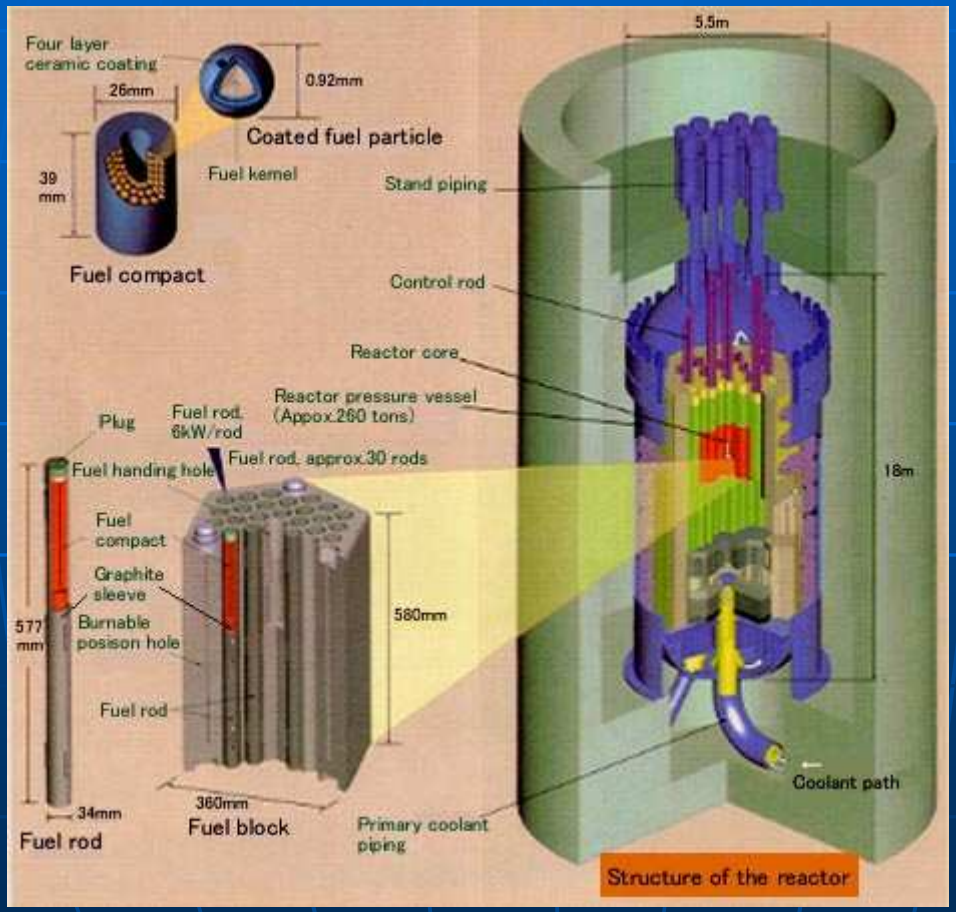
THE NEW REACTORS

NON-LWR NEW REACTORS

- **GT-MHR,** Gas Turbine Modular Helium Reactor, General Atomics, 285 MWe
  - High Temperature Gas-cooled Reactor
  - Status: Pre-application Review By USNRC
  - Potential Plans To Build GT-MHRs In Russia For the Disposal Of Surplus Plutonium Supplies
  - Design Calls for HEU (19.9% <20% U^{235} Enrichment)
  - GT-MHR Viewed as a Potential Commercial Heat Source Due to High Coolant Temperatures
  - USDOE Views GT-MHR as Next Generation Nuclear Plant (NGNP) Program

THE NEW REACTORS

GT-MHR



THE NEW REACTORS

PBMR Pebble Bed Modular Reactor

- High Temperature Gas-Cooled Reactor
- 165 MWe – One of the Smallest New Reactors
- Part of HTGR Family of Reactors
- Uses Helium as Coolant – Higher U^{235} Enrich. Than LWRs
- Pre-Application Review
- Prototype Variations of PBMR in Operation in China and Japan
- No U.S. Company Sponsor
- Westinghouse Minority Partner with Eskom, S.A. Utility Taking the Lead

FACT SHEET

- 441 Power Reactors in 31 Countries Generating Electricity for 1 Billion People
- 81% (357) of All (439) Reactors Are LWRs
  - 74% (263) Are PWRs – Several Vendors
  - 26% (94) Are BWRs – One Vendor (GE)
- 17% of World Electricity Generation
- Half or More Electricity in Many Industrialized Countries
- 32 Reactors Presently Under Construction

NEW REACTORS
CONCLUSIONS

- Proven and Mature Technology
- Enhanced Safety Features
  - Safer By Design
  - Passive Safety
- Simplified & Standardized Design
- Economical to Build, Operate and Maintain
- Cost Less Than Older Generations Designs