US-APWR
Pre-Application Review Meeting

July 13, 2006

Mitsubishi Heavy Industries, Ltd.

Contents

1. US-APWR Design Certification Activity

Objectives of Pre-Application Review

- To familiarize the NRC with US-APWR
- To clarify potential issues for the NRC in US-APWR Design Certification application
- To identify any new issues of concern for the NRC
- To prepare Design Control Document of US-APWR for Design Certification application
- To submit US-APWR Design Certification application

Today's Meeting Objectives

- To provide the NRC with a better understanding of Mitsubishi nuclear worldwide activities
- To familiarize the NRC with main features of US-APWR design
- To communicate MHI plans for pre-application review of US-APWR design certification and to obtain feedback from the NRC
- To establish future plan

2. Introduction of Mitsubishi Nuclear Activities

Mitsubishi: Experienced and Integrated Nuclear Plant Supplier

US-APWR

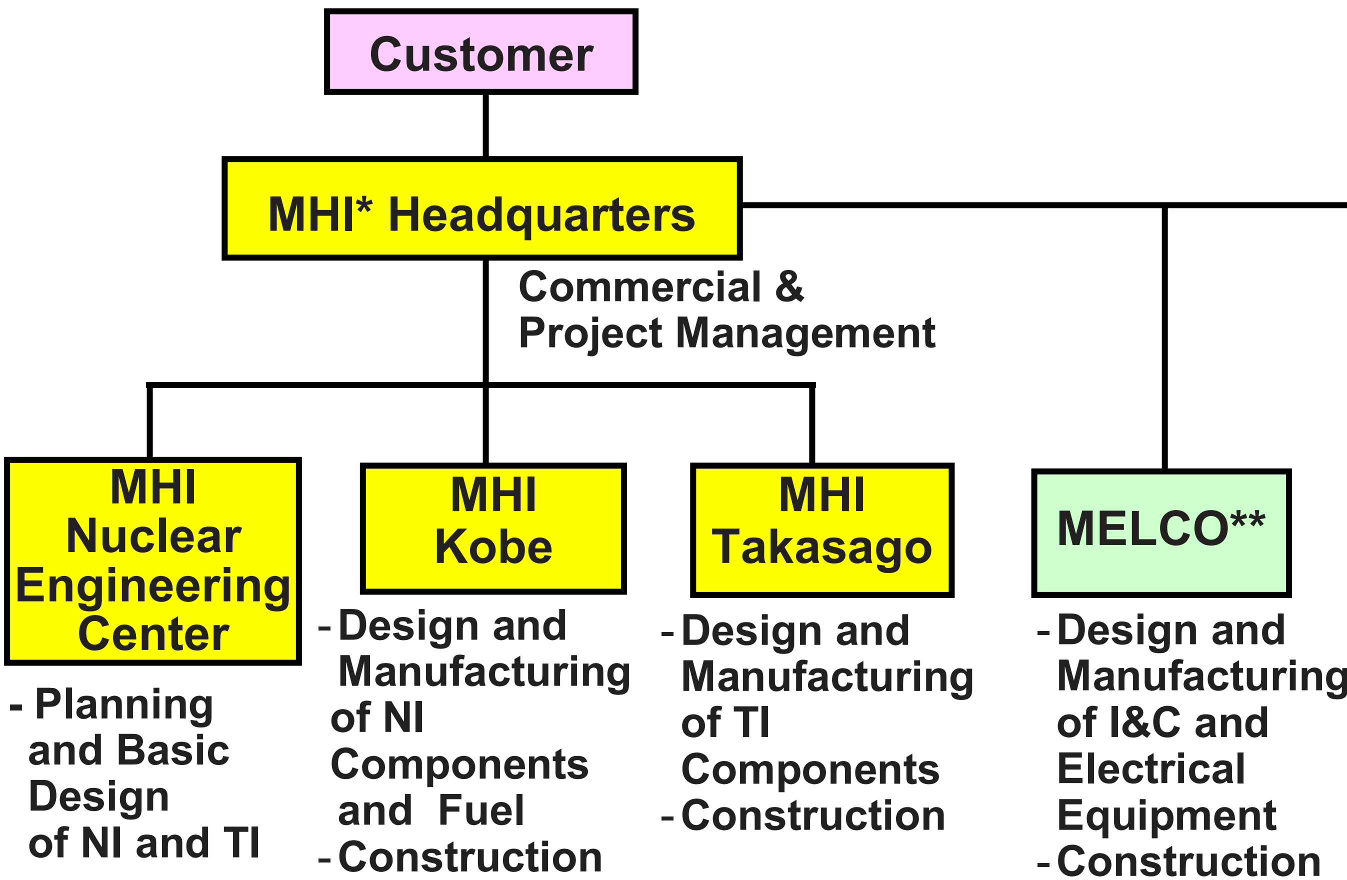
Mitsubishi has accumulated vast experiences in supplying reliable products and services in the areas of

- **PWR Nuclear Power Plants**
  - ✓ Design, Manufacture, Construction, Maintenance/Repair Services
- **Nuclear Fuel**
  - ✓ PWR Fuel, Advanced Reactor Fuel, Non-Fuel Core Components
- **Advanced Reactor Plants**
  - ✓ Fast Breeder Reactor, High Temperature Gas Cooled Reactor, Nuclear Fusion Reactor
- **Nuclear Fuel Cycle Equipment/Components**
  - ✓ Spent Fuel Reprocessing Facilities, Waste Disposal System Equipment, Radioactive Material Transport Cask, Uranium Enrichment Device

Mitsubishi Nuclear Organization

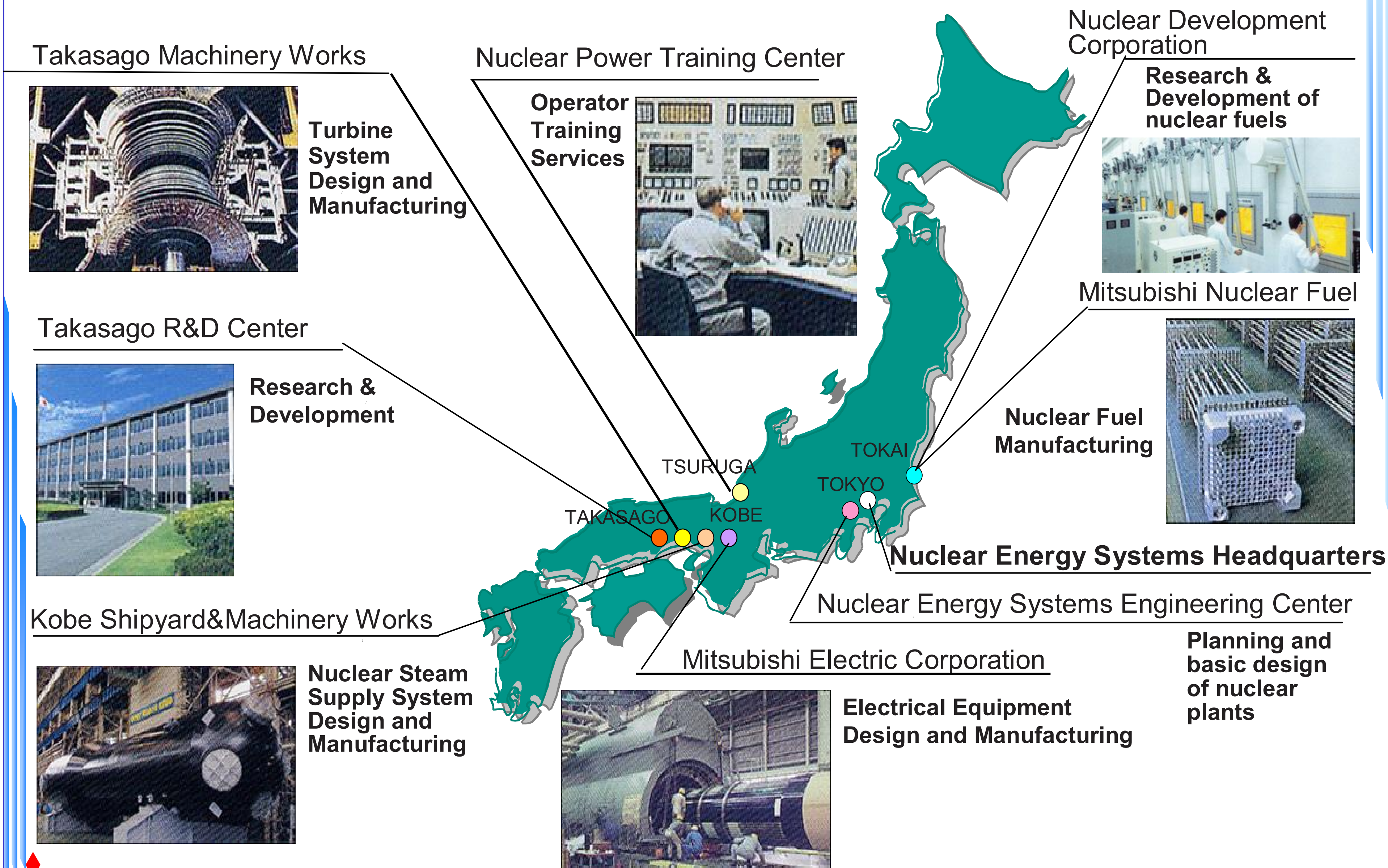
Capability to construct NPPs on a turn - key basis

- Responsible for a Whole Plant
- Utilize Enhanced Technology and Total Management Capability



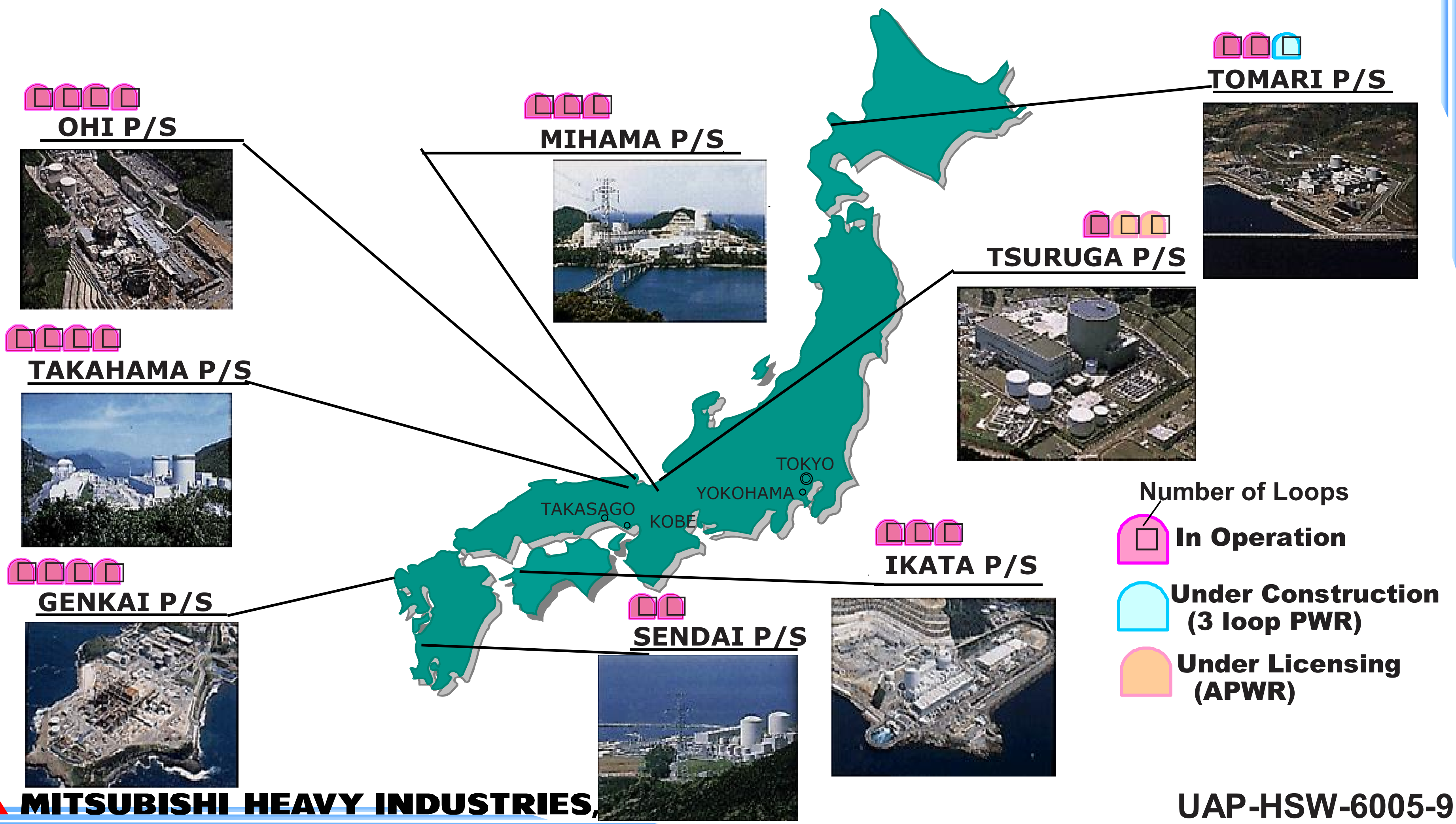
MHI*:
Mitsubishi Heavy Industries
MELCO** :
Mitsubishi Electric Corporation

Mitsubishi Nuclear Organization



Experiences of PWR Constructions in Japan

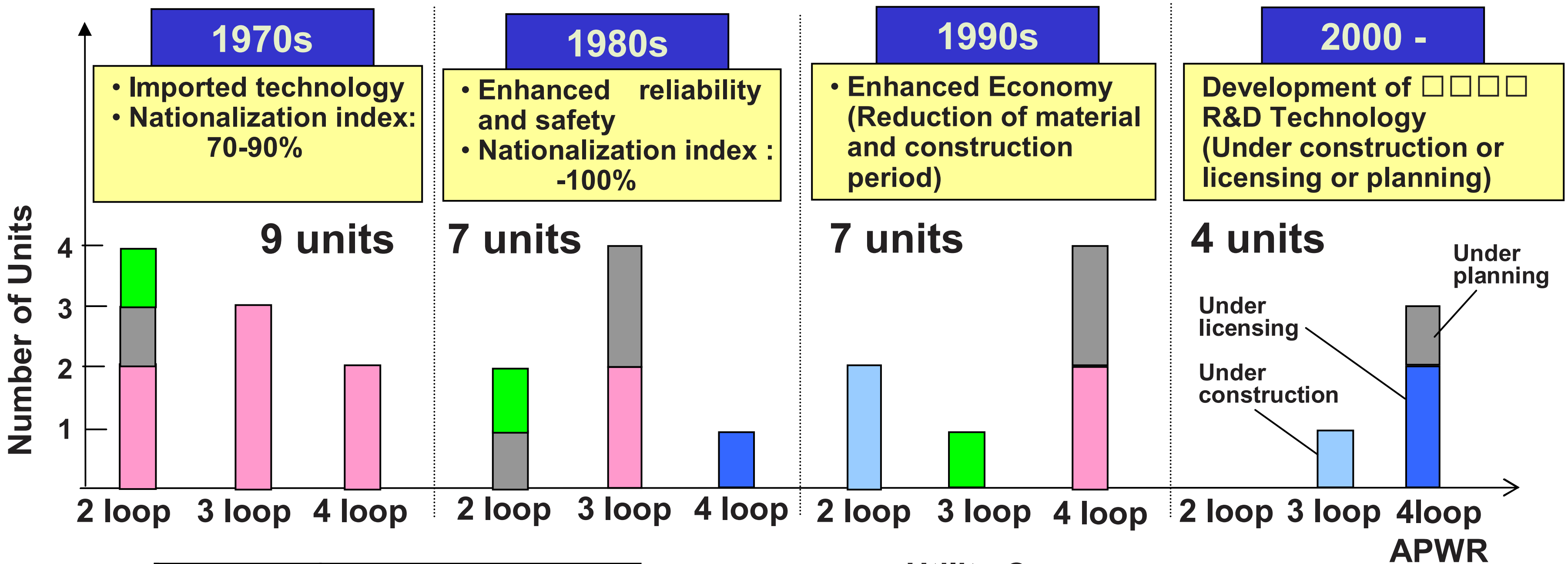
- Mitsubishi has constructed 23 PWR NPPs.
- The 24th PWR plant is under construction.
  A twin APWR is under licensing.



Development of Mitsubishi PWR Technology

Mitsubishi has been continuously upgrading its designs and engineering from those imported.

- The first units for 2 Loop, 3 Loop and 4 Loop utilized technology transferred to Mitsubishi with final design collaboratively engineered.
- The following 19 were designed, manufactured, and constructed by Mitsubishi.



	Number of Units
2 Loop	8
3 Loop	9
4 Loop	10

Utility Company

- : Japan Atomic Power
- : Hokkaido
- : Kansai
- : Shikoku
- : Kyusyu

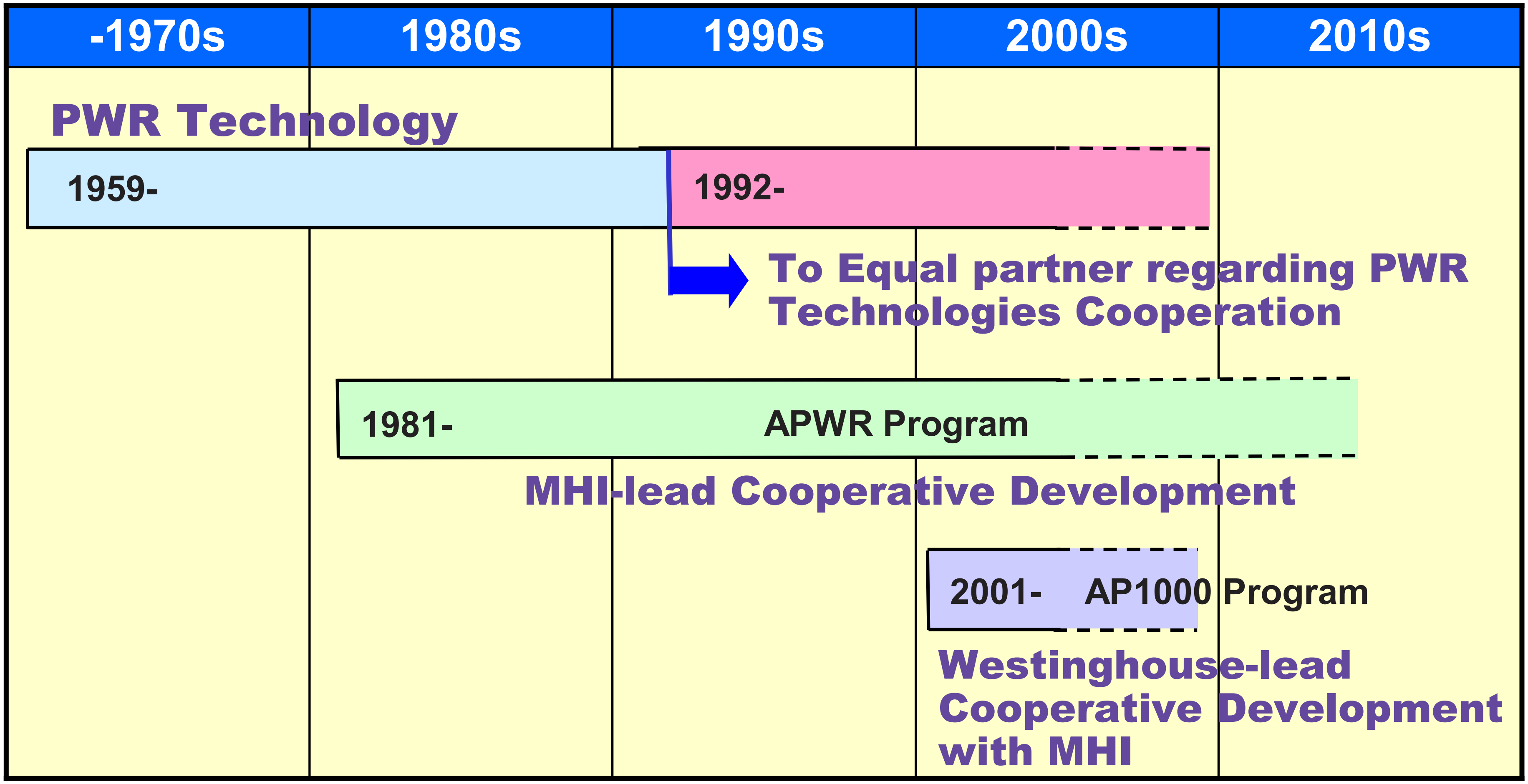
Line-up of Mitsubishi PWR Plant

Mitsubishi has the Latest Reference PWR Plant in each Power Output Class.

Number of Loops	Output of Electric Power	Reactor Vessel	Number of Fuel Assembly	Steam Generator/ Reactor Coolant Pump	Reference Plant
2 Loop	600 MWe Class	I.D. 11.15 ft (3.4 m)	121 Assemblies	Standard	Tomari Units 1 & 2 (Commercial Operation : 6/1989 & 4/1991)
3 Loop	900 MWe Class	I.D. 13.12 ft (4.0 m)	157 Assemblies	Standard	Ikata Unit 3 (Commercial Operation : 2/1995) Tomari Unit 3 (Under Construction)
4 Loop	1200 MWe Class	I.D. 14.44 ft (4.4 m)	193 Assemblies	Standard	Genkai Units 3 & 4 (Commercial Operation : 3/1994& 7/1997)
4 Loop (APWR)	1500 MWe Class	I.D. 17.06 ft (5.2 m)	257 Assemblies	Larger Capacity but same concept	Tsuruga Units 3 & 4 (Under licensing)

Relationship between MHI and Westinghouse regarding PWR Technology

MHI Established Complete PWR Design and Supply Capability Starting from Westinghouse Technology Licenses.



MHI Nuclear Export Experience

US-APWR

Asia

	Plant	Delivery
Reactor Vessel	Qinshan I (CHINA)	1986
	Qinshan II #1 (CHINA)	1999
Rector Vessel Closure Head	KEDO #1 (KOREA)	Under Suspension
	KEDO #2 (KOREA)	Under Suspension
Reactor Coolant Pump	Qinshan II #1 (CHINA)	1999
	Qinshan II #2 (CHINA)	2001
	Qinshan II #3 (CHINA)	(2009)
	Qinshan II #4 (CHINA)	(2010)
Main Turbine	Taiwan 4 th Nuclear Power Station #1 (TAIWAN)	(2006)
	Taiwan 4 th Nuclear Power Station #2 (TAIWAN)	(2006)

America

	Plant	Delivery
Reactor Vessel Closure Head	Surry #2	2003
	Kewaunee	2004
	Farley Unit #1	2004
	Farley Unit #2	2005
	H. B. Robinson	2005
	Millstone #2	2005
	Point Beach #1	2005
	Point Beach #2	2005
	Prairie Island #2	2005
	Prairie Island #1	2005
	Fort Calhoun	2006
	South Texas PJ#1	(2009)
	South Texas PJ#2	(2010)
	San Onofre #2	(2011)
	San Onofre #3	(2012)
Pzr	Fort Calhoun	2006
Steam Generator	Fort Calhoun	2006
	San Onofre #2	(2008)
	San Onofre #3	(2009)
Main Turbine	Laguna Verde #1 (MEXICO)	1975
	Laguna Verde #2 (MEXICO)	1975

Europe

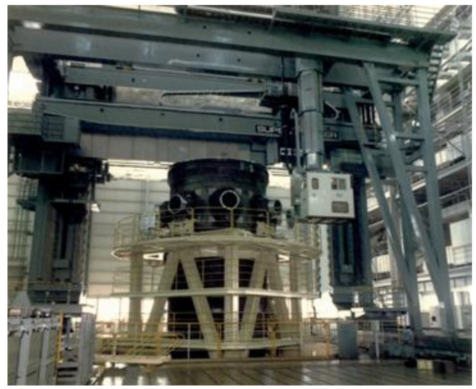
	Plant	Delivery
Reactor Vessel	Olkiluoto #3 (FINLAND)	(2006)
Reactor Vessel Closure Head	Ringhals #2 (SWEDEN)	1996
	Ringhals #3 (SWEDEN)	2004
	Ringhals #4 (SWEDEN)	2005
Steam Generator	Tihange #1 (BELGIUM)	1995
	Tihange #2 (BELGIUM)	2001
	Doel #2 (BELGIUM)	2004
	Unit F (FRANCE)	(2008)
	Unit G (FRANCE)	(2008)
Simulator	Novovoronezh Training Center (RUSSIA)	1996
Main Turbine	Vandellos #2 (SPAIN)	1999
	Krsko (SLOVENIA)	2006

Mitsubishi PWR Technologies

US-APWR

Mitsubishi is doing broad and integrated business activities from research & development, design, manufacture, construction through maintenance related to PWR plants.

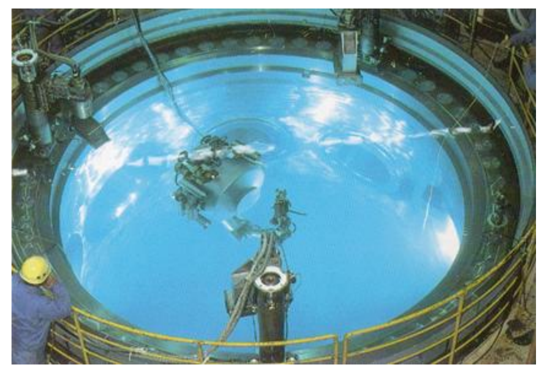
Design



Manufacture

Construction

Research and Development

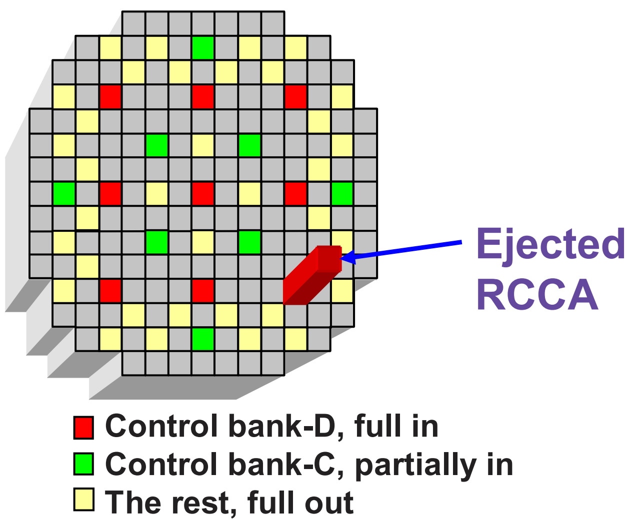


Maintenance

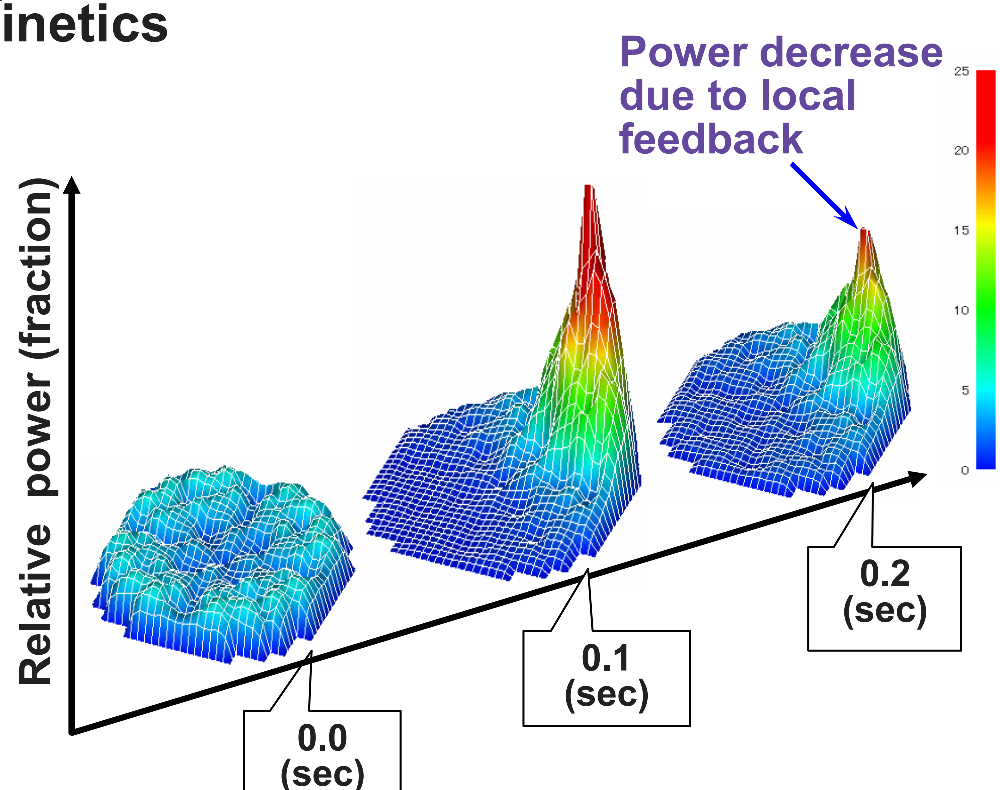
Design
- Core and Safety Analysis-

Mitsubishi has highly developed computational analysis technology.

- ➢A sample of computational analysis results
  - ✓Local power distribution analysis during rod ejection accident
  - ✓More realistic safety evaluation method applying 3-D core kinetics

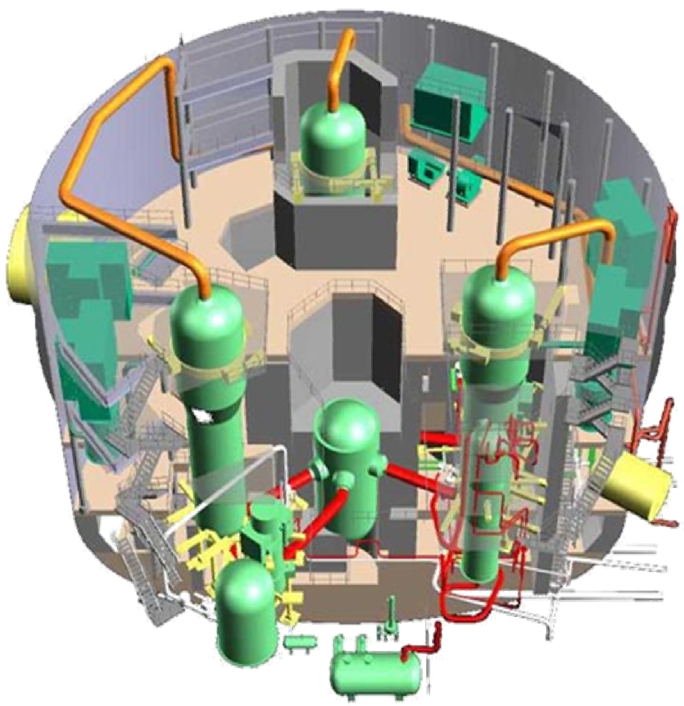


Control rod insertion pattern of 4 loop PWR plant

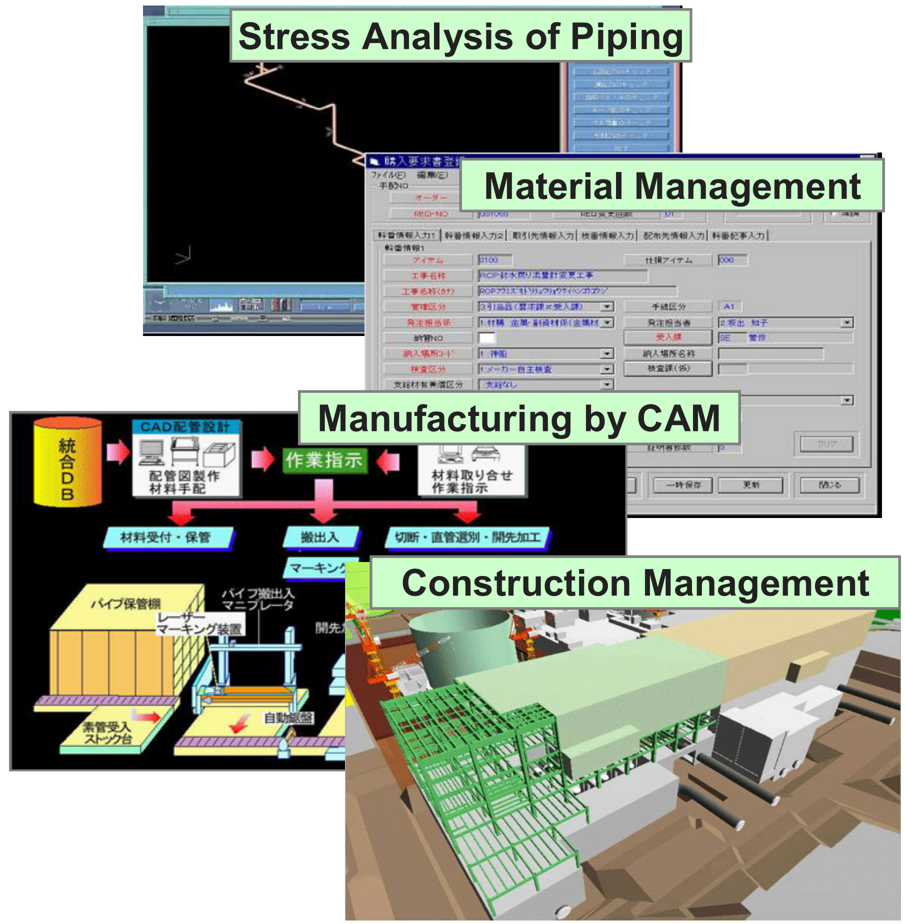


Design
- Plant Engineering -

Mitsubishi streamlines all of its processes from initial basic design to manufacture/construction using a seamless design information management system (CAD/CAM systems).



Integrated Database

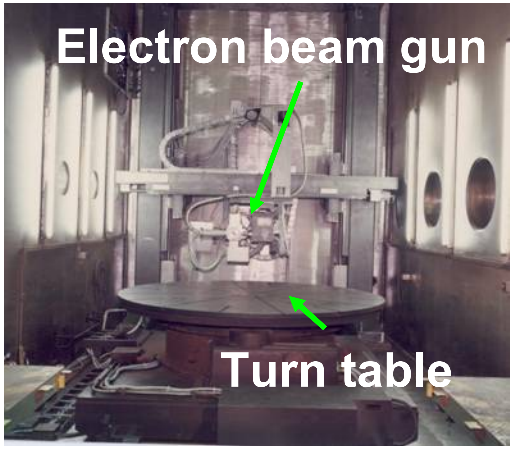


Manufacturing

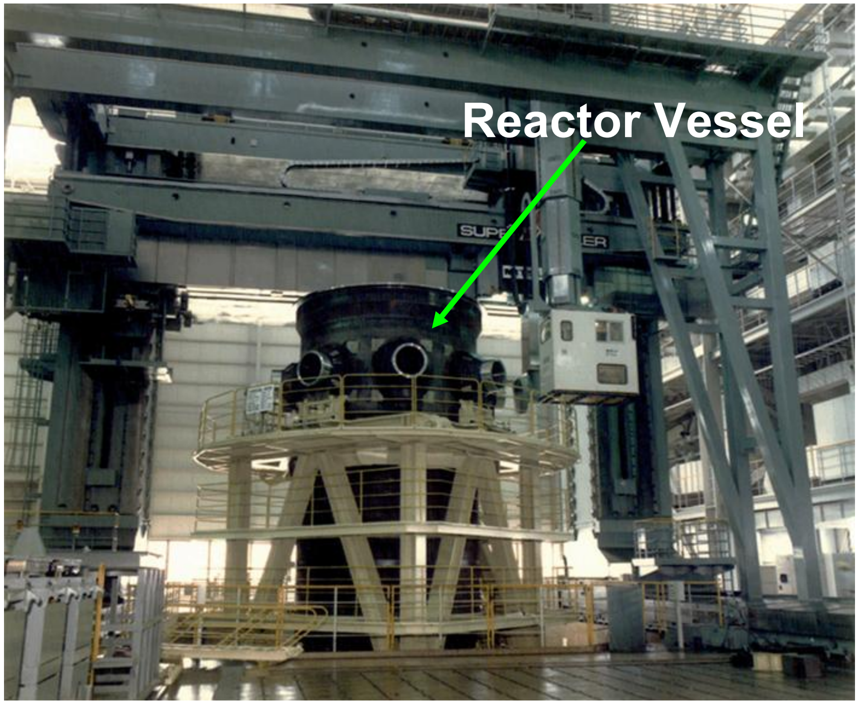
Mitsubishi encourages technical innovation and maintains its efforts to update its technologies at all times with high accuracy, efficiency, and reliability.

6000 ton Hot press forming

150kW Electron beam welding machine

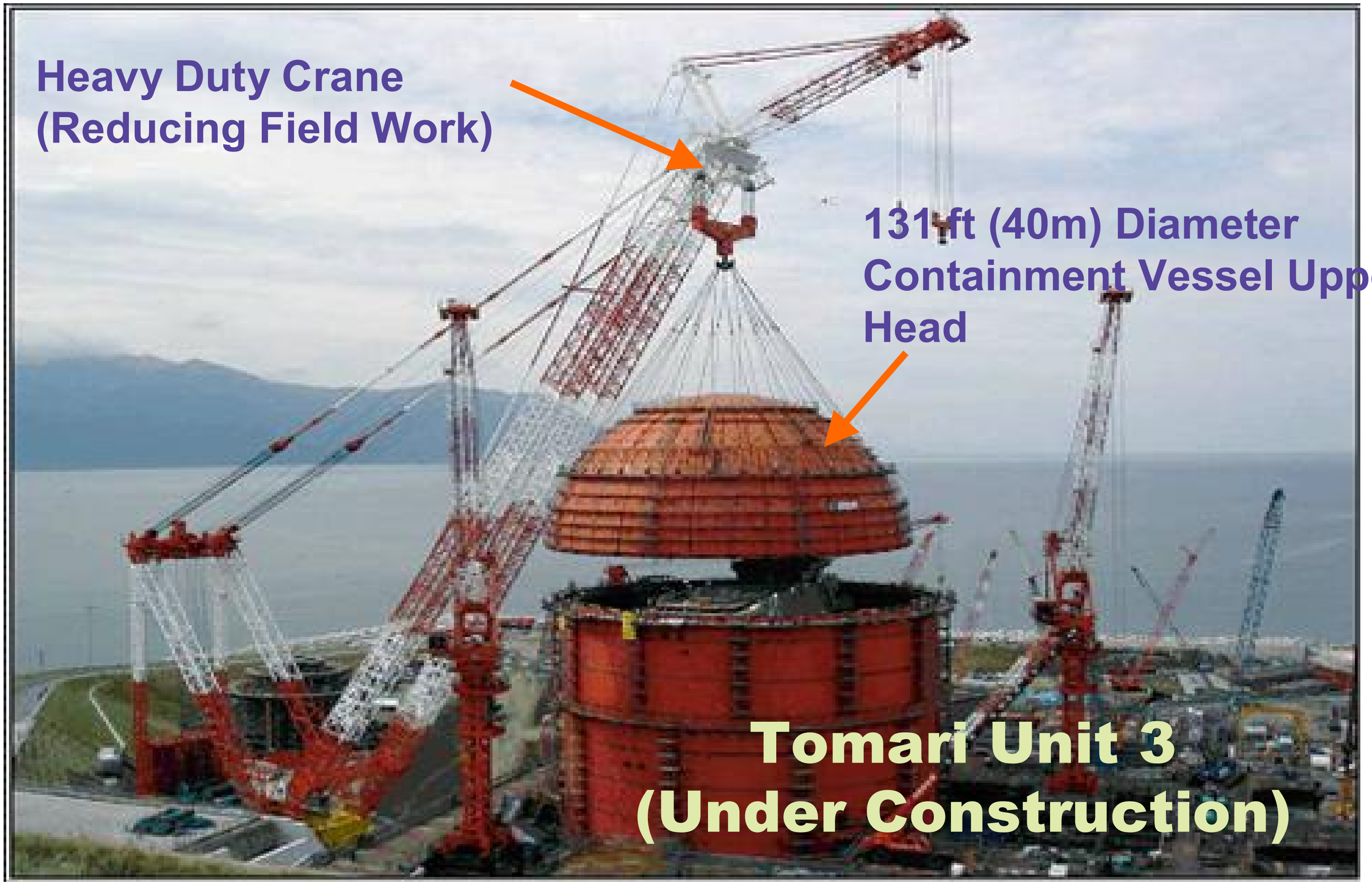


Super large Multi- functional NC- machine "Super Miller"



Construction

Mitsubishi has introduced advanced construction methods to construct the best possible plant in the minimum delivery time.



Operation and Maintenance

Even after the plant has been installed, Mitsubishi keeps watch over its equipment with the rich experience and advanced technology which has been developed to ensure smooth operation.

Replacement of Lower Reactor Internals

Replacement of Steam Generator

Replacement of Main Control Board

Improvements in reliability and extension of plant life

Improvements in operability

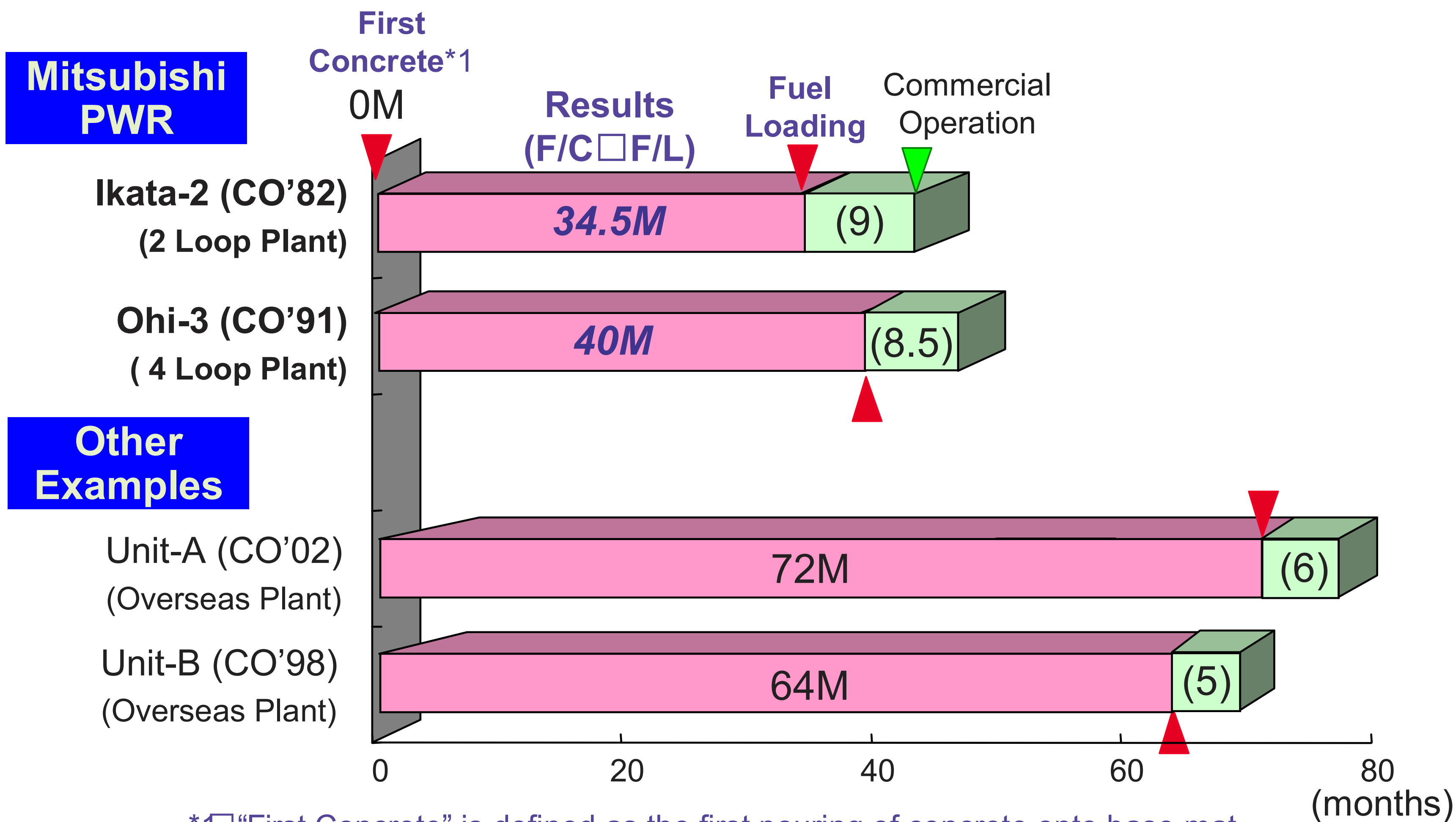
Excellent Performance

Leading Technology of PWR plant based on turn-key PWR plant construction experiences

- ➢ Excellent Construction Performance
  (Quality, Cost, and Delivery)
  - ✓ 40 months construction period from the first concrete to fuel loading, for Ohi Unit 3, the latest 4 loop PWR plant.
- ➢ Excellent Reliability
  - ✓ Unscheduled Plant Shutdown
    Less than 0.1 time/year
  - ✓ Low Fuel Leakage
    Recent experience of no fuel leakage for 13 years

Excellent Performance

Short Construction Period Experience of Mitsubishi PWR



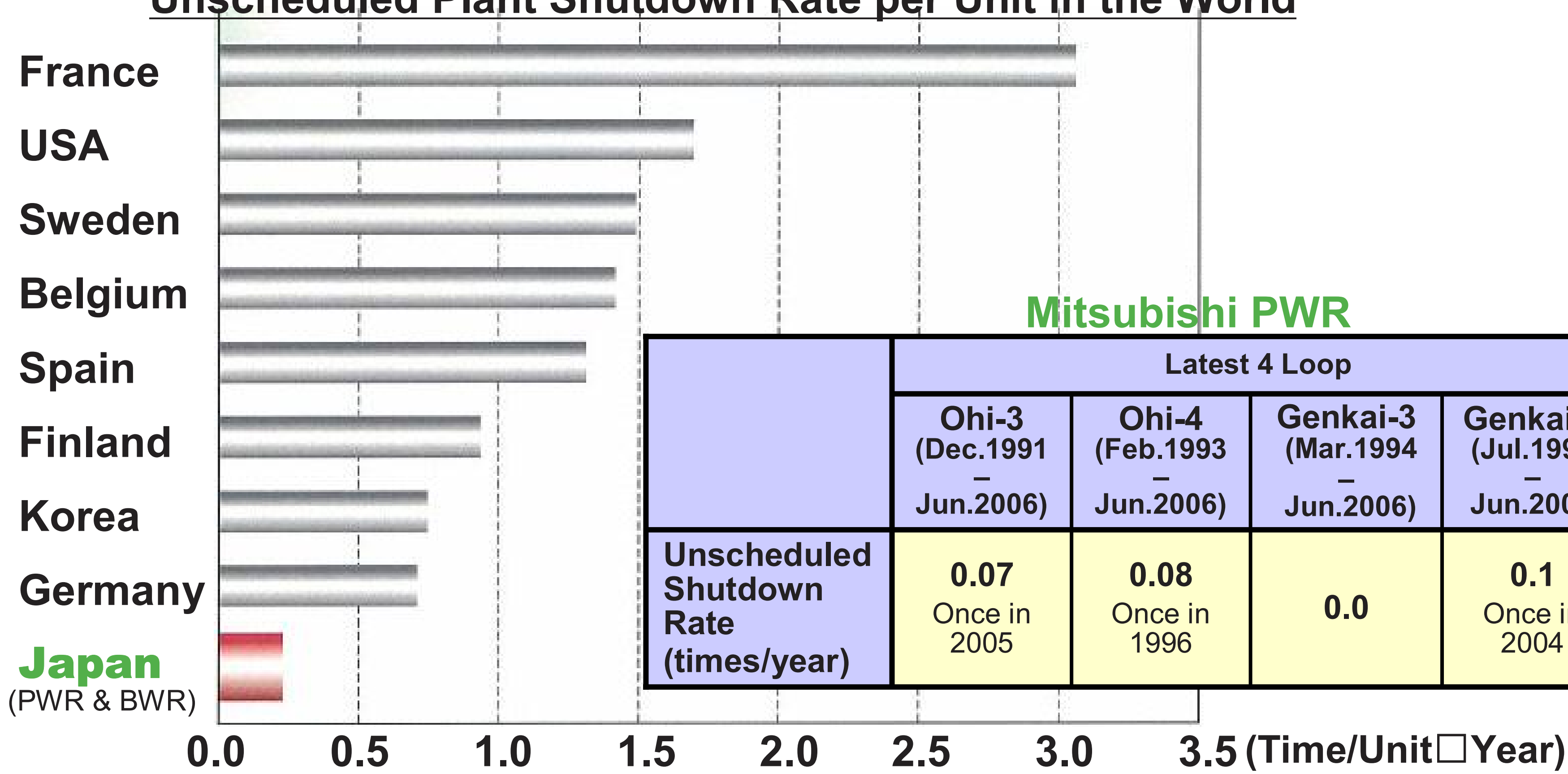
*1□"First Concrete" is defined as the first pouring of concrete onto base mat

CO□Commercial Operation

Excellent Performance

Unscheduled Plant Shutdown of Mitsubishi PWR: Less than 0.1 time/year

Unscheduled Plant Shutdown Rate per Unit in the World



Mitsubishi PWR

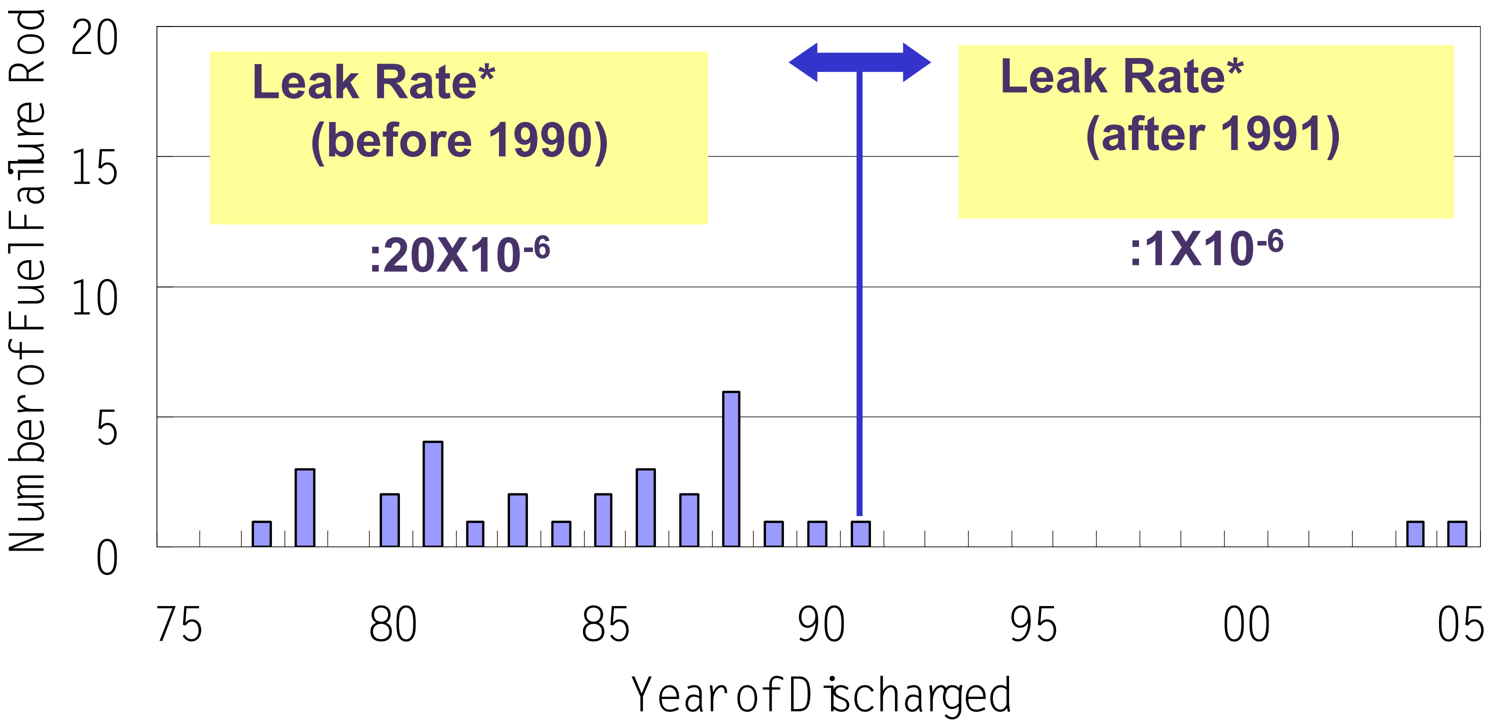
	Latest 4 Loop			
	Ohi-3 (Dec.1991 – Jun.2006)	Ohi-4 (Feb.1993 – Jun.2006)	Genkai-3 (Mar.1994 – Jun.2006)	Genkai-4 (Jul.1997 – Jun.2006)
Unscheduled Shutdown Rate (times/year)	0.07 Once in 2005	0.08 Once in 1996	0.0	0.1 Once in 2004

Note : Unscheduled Outage Data are Average Values of the years 1994-2003
Reference : Japan Nuclear Energy Safety Organization (JNES)
Original Data Source: IAEA-PRIS (Power Reactor Information System) Data

Excellent Performance

- Number of Fuel Assemblies supplied by Mitsubishi is over 17,000 as of May 2006
- Low Fuel Leakage; Recent experience - no fuel leakage for 13 years

Only two fuel leakages have been observed since early 90's

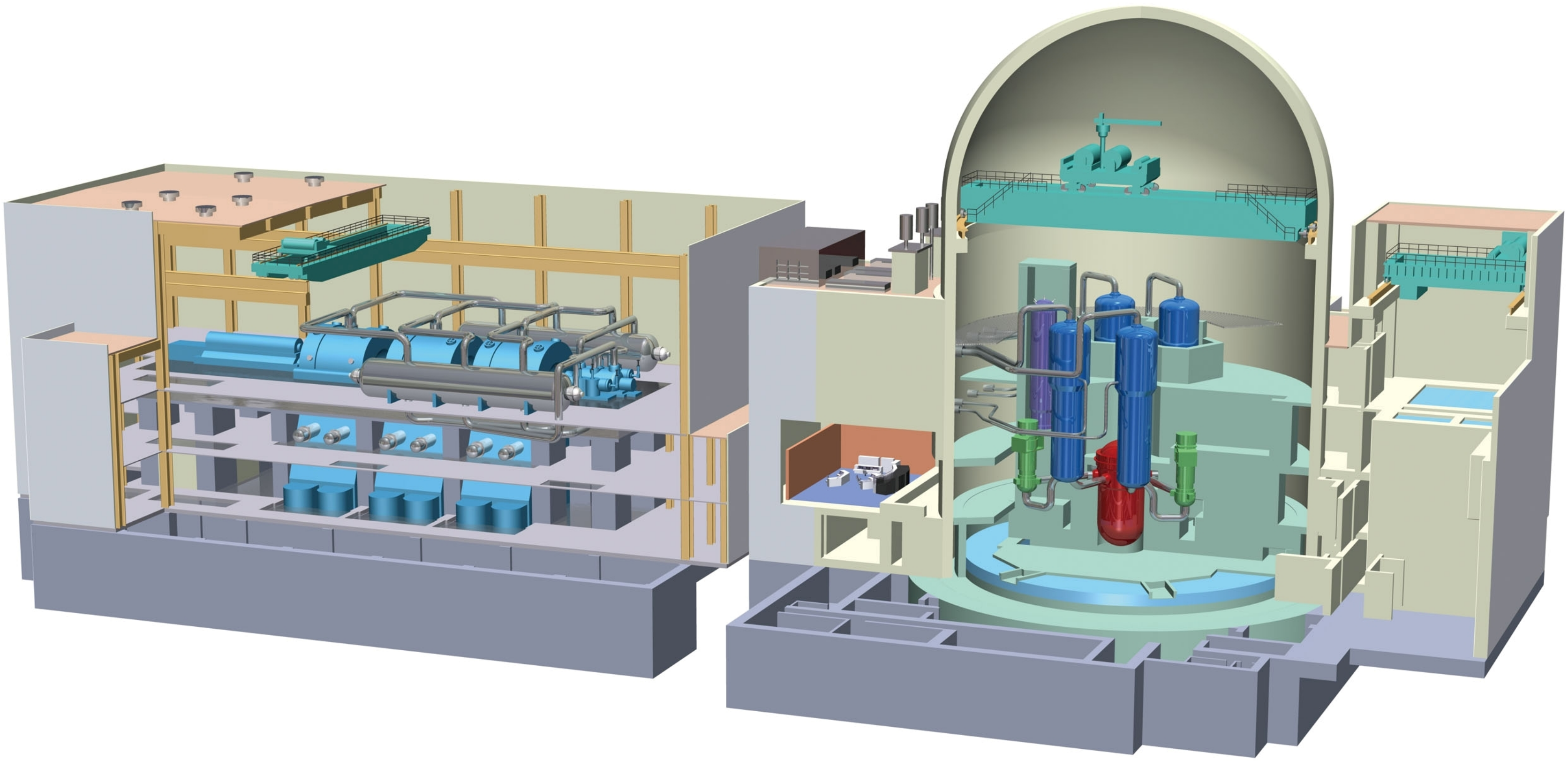


*Leak Rate : Number of leaked rods / Total number of fabricated rods

Summary

- Mitsubishi's current nuclear business activities span research & development, design, manufacture, construction and plant maintenance.
- Mitsubishi incorporated Westinghouse PWR technology and has evolved it for the APWR plants.
- Mitsubishi PWR plants have achieved excellent performance with high reliabilities.
- Mitsubishi is constructing the 24^{th} PWR plant (Tomari-3) in Japan and is getting ready for construction of a twin APWR plant (Tsuruga-3/4).
- Mitsubishi is providing the engineering and manufacturing of Replacement Steam Generators, Reactor Vessel Heads, Reactor Internals, Turbine Rotors, Main Control Boards, etc. worldwide.

3.US-APWR Overview



3.1 Main Features of US-APWR

What is US-APWR

- Basic design concept of US-APWR is same as APWR.
- New technologies of APWR are fully tested, well-verified and established.
- US-APWR, 1700MWe class, is based on the established APWR technology with
  - ✓ Latest technologies to improve plant efficiency
  - ✓ Minor modifications to meet U.S. utility requirements

Main features of US-APWR

Plant Parameters and Major components

		Current 4 Loop	APWR	US-APWR
Electric Output		1,180 MWe	1,538 MWe	1,700 MWe Class
Core Thermal Output		3,411MWt	4,451 MWt	4,451 MWt
Steam Generator	Model	54F	70F-1	91TT-1
	Tube size	7/8”	3/4”	3/4”
Reactor Coolant Pump	Model	93A-1	100A	100A
Turbine	LP last-stage blade	44 inch	54 inch	70 inch class

- **APWR**
  - ✓1538MWe output is achieved by large capacity core and large capacity main components such as SG, RCP, turbine, etc.
- **US-APWR**
  - ✓1700MWe class output is achieved from a 10% higher efficiency than APWR.
    - Same core thermal output with APWR
    - High-performance, large capacity steam generator
    - High-performance turbine

Main features of US-APWR

Reactor Core and Internals

		Current 4 Loop	APWR	US-APWR
Core Thermal Output		3,411MWt	4,451 MWt	4,451 MWt
Core and Fuel	NO. of Fuel Assem.	193	257	257
	Fuel Latice	17×17	17×17	17×□□
	Active Fuel Length	12ft	12ft	14 ft
Reactor internals		Baffle/former structure	Neutron Reflector	Neutron Reflector
In-core Instrumentation		Bottom mounted	Bottom mounted	Top mounted

- **APWR**
  - ✓ Large capacity core by increasing number of fuel assemblies
  - ✓ Installation of neutron reflector to enhance reliability and fuel economy
- **US-APWR**
  - ✓ Low power density core using 14ft. fuel assemblies with the same reactor vessel as APWR to enhance fuel economy for 24 months operation
  - ✓ Enhanced reliability and maintainability of reactor vessel by top mounted ICIS

Main features of US-APWR

Safety system and I & C

			Current 4 Loop	APWR	US-APWR
Safety Systems	Trains	Electrical	2 trains	2 trains	4 trains
		Mechanical	2 trains	4 trains	4 trains
	Systems	HHSI pump	100% × 2	50% × 4(DVI)	50% × 4(DVI)
		LHSI pump	100% × 2	-	-
		ACC	4	4 (Advanced)	4 (Advanced)
	RWSP		Outside CV	Inside CV	Inside CV
Containment Vessel			PCCV	PCCV	PCCV
I & C	Control Room		Conventional	Full Digital	Full Digital
	Safety I&C		Conventional		
	Non-Safety I&C		Full Digital		

➢ **APWR**
- ✓ Enhanced safety by simplified and reliable safety systems
  - Mechanical 4 train systems with direct vessel injection design
  - Elimination of LHSI pump by utilizing advanced accumulators
  - Elimination of recirculation switching by In-containment RWSP

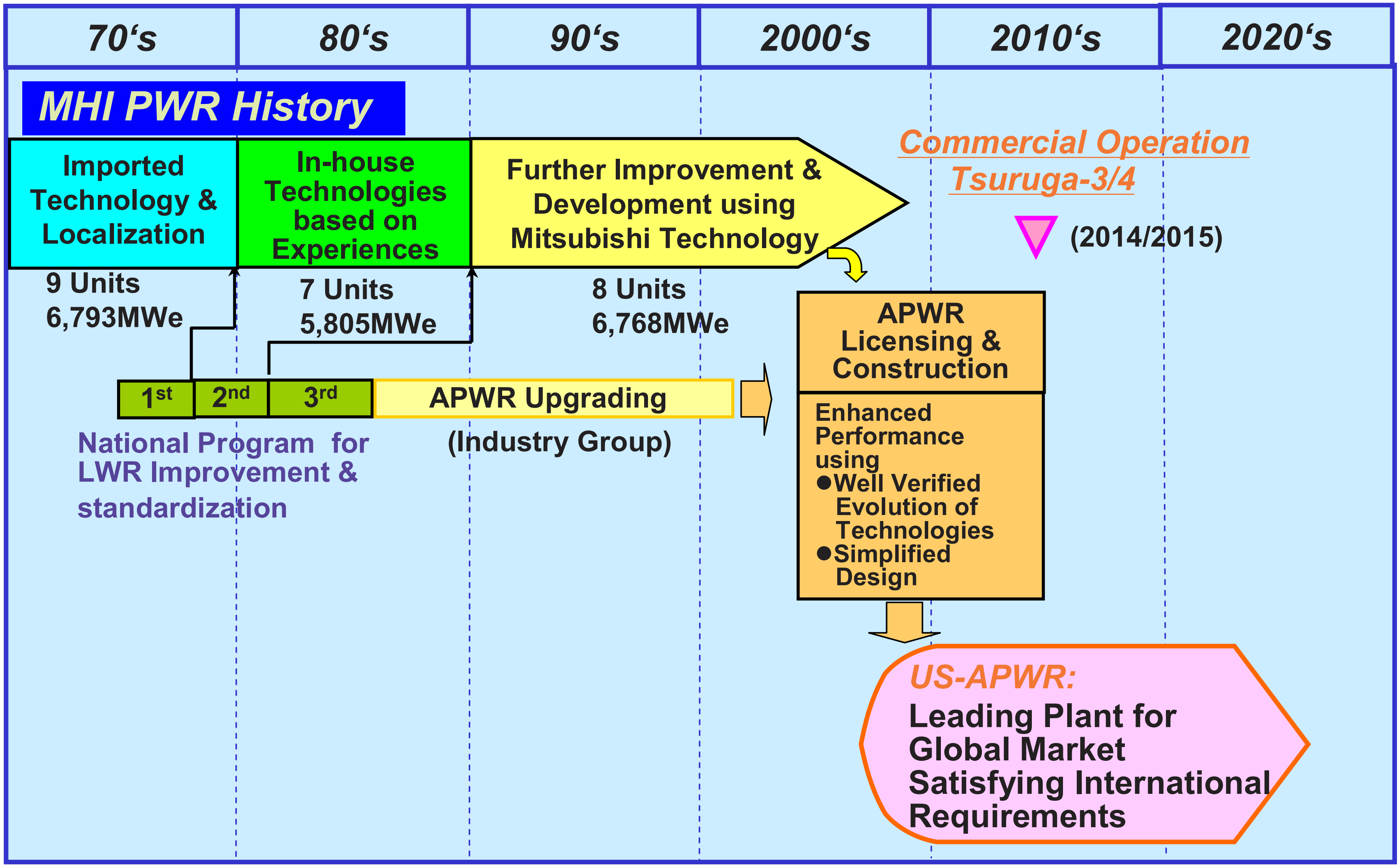
➢ **US-APWR**
- ✓ Enhanced safety by 4 train safety electrical systems
- ✓ Enhanced on line maintenance capability

Summary of Main features of US-APWR

- Enhanced Economy
  - ✓Large capacity and high plant performance
  - ✓High fuel performance for 24 months operation
- Enhanced Safety
  - ✓Cope with safety, operability and economy using advanced technologies
- Enhanced Reliability
  - ✓Well designed and verified proven technologies

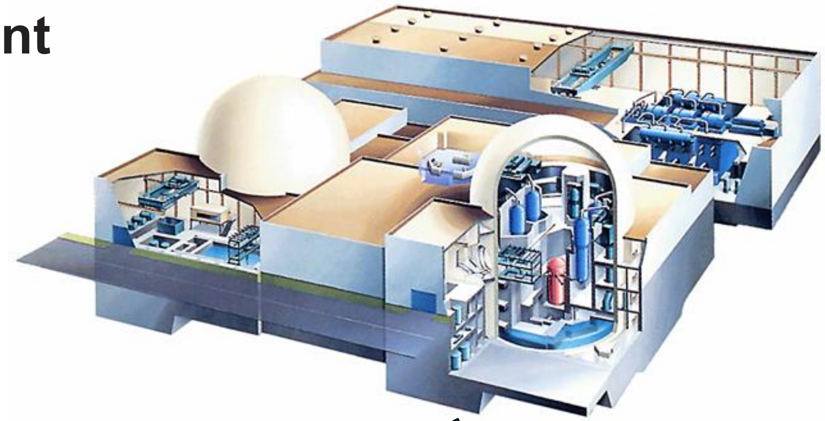
3.2 New Design Features of APWR

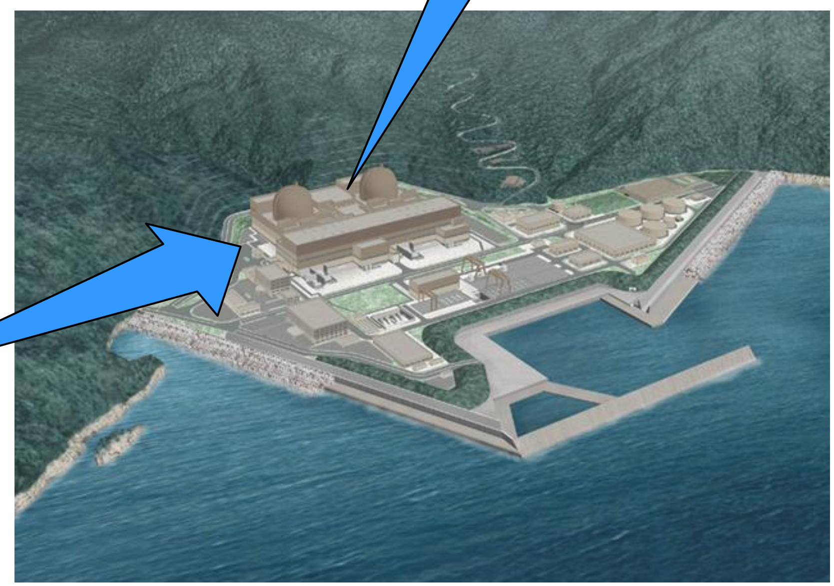
APWR Development



The First APWRs (Tsuruga3/4)

- Application for Reactor Establishment License: March, 2004
- Commercial Operation
  - Unit 3 : 2014
  - Unit 4 : 2015

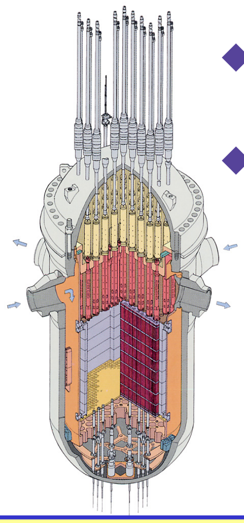




(From web-site of the Japan Atomic Power Company)

Advanced Technologies

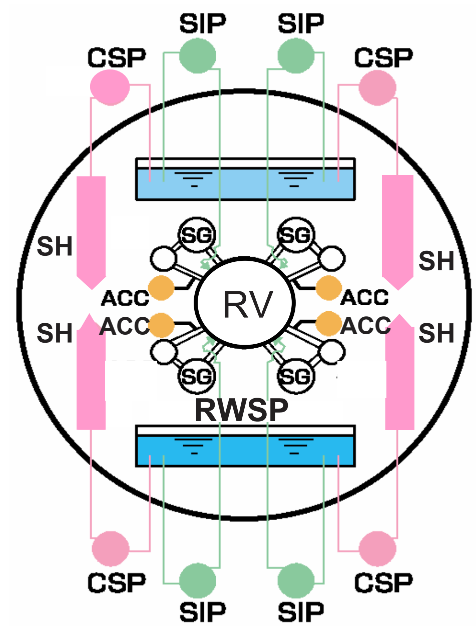
Reactor



◆1500 MWe class large capacity

◆Neutron reflector

Engineering Safety Features



◆Simplified configuration with 4 mechanical sub-systems

◆In-containment RWSP

◆Advanced accumulator

Steam Generator

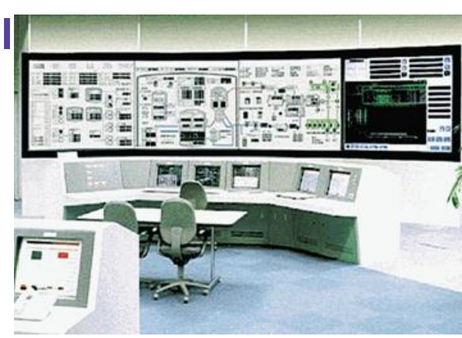
◆High performance separator

◆Increased capacity with compact sizing

I & C

◆Digital control & protection systems

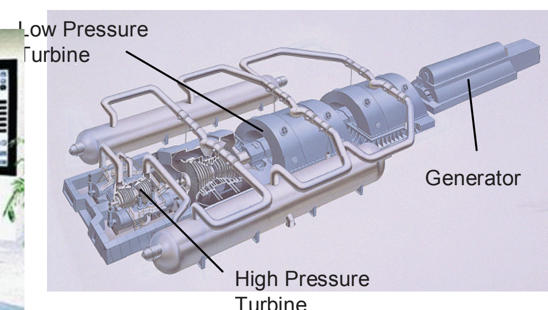
◆Compact console



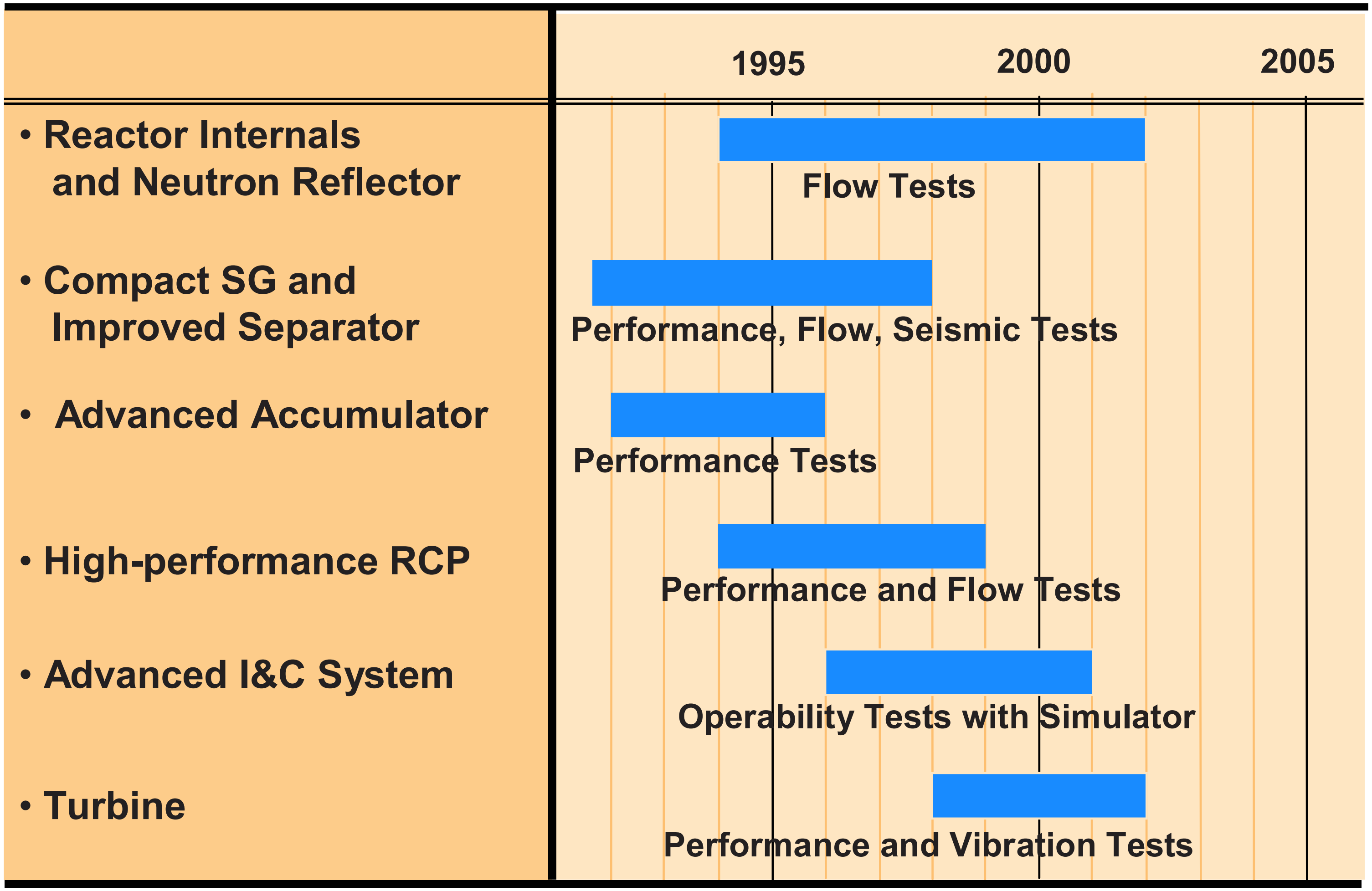
Turbine

◆54 inch-length blades in LP turbine

◆Fully integrated LP turbine rotor



Verifications for Advanced Designs




Reactor Flow Test


SG Separator Test

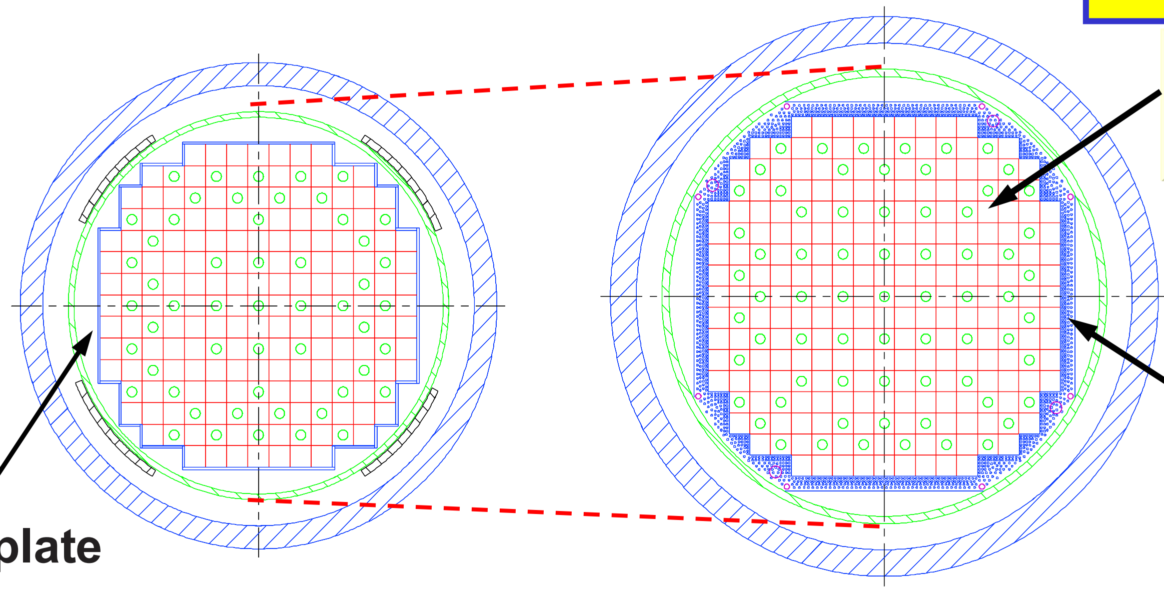

LP Turbine Test

Core Design

US-APWR

Standard 4 Loop PWR **APWR**

Larger Thermal Output



Baffle plate

Increased Fuel Assemblies

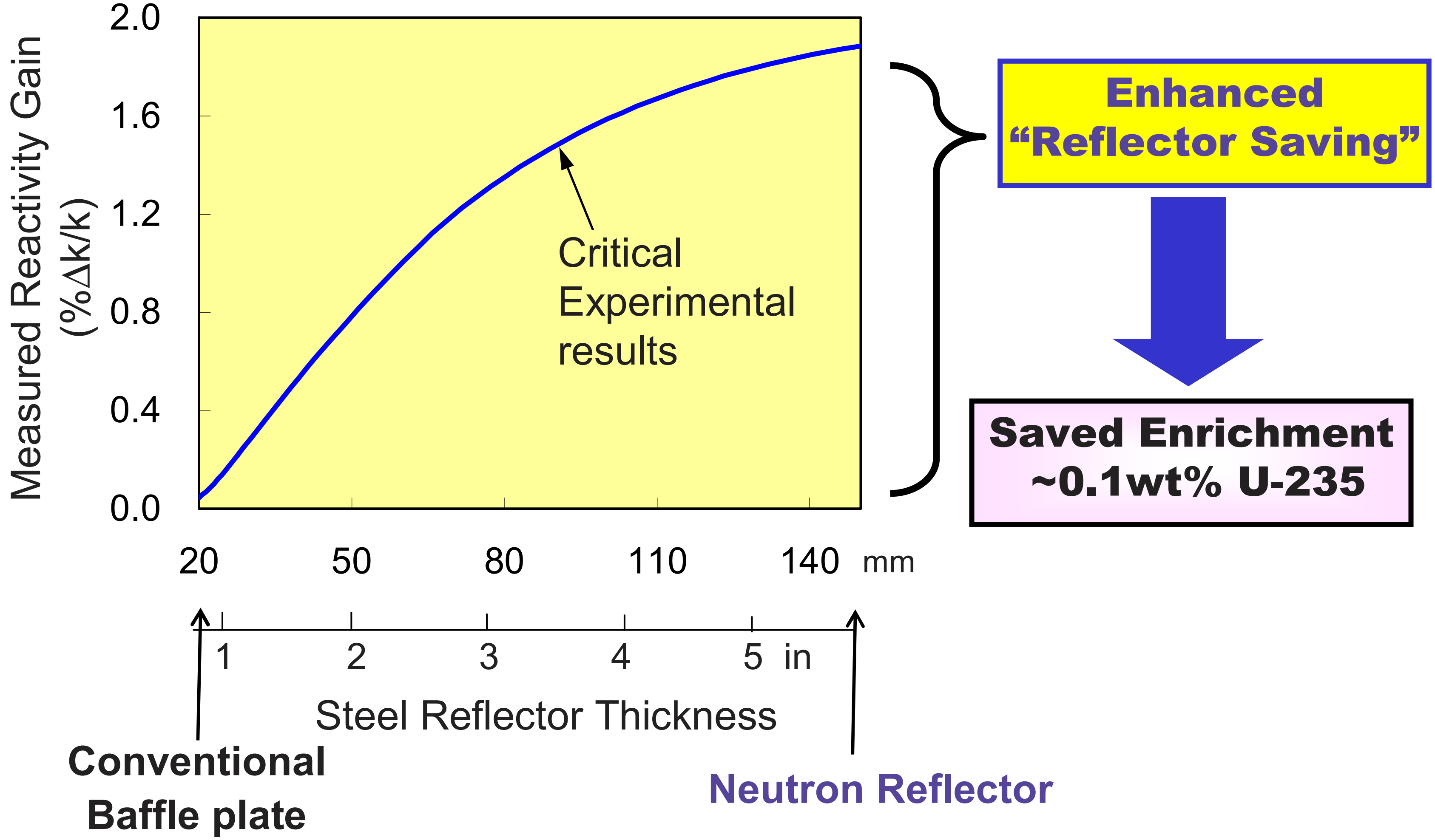
Improved Neutron Economy

Neutron Reflector

	Std. 4 Loop	APWR
Core Thermal Output	3,411MW□	4,451MW□
No. of Fuel Assemblies	193	257
Core Equivalent Dia.	11 ft (3.4m)	13 ft (3.9m)
Active Core Height	12 ft (3.7m)	12 ft (3.7m)

Core Design

Neutron Reflector Saves Uranium



Fuel Design

Enhance Fuel Economy

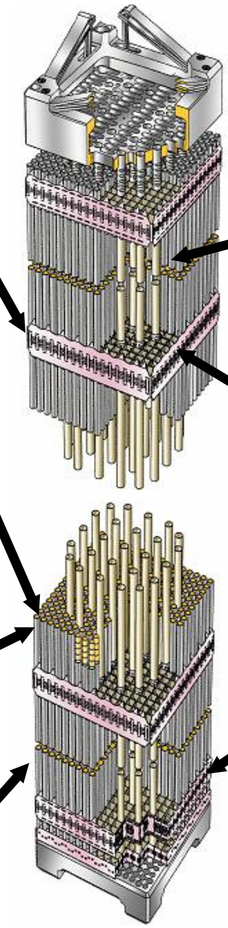
Zircalloy Grid
□Improve Neutron Economy□

Higher Density Pellet
□97%TD*□

Enable Flexible Core Operation

Higher Gadolinia Content Pellet□10wt%□

Larger Plenum Volume
□Reduction of Internal Pressure□



Improve Reliability

Corrosion Resistant Cladding Material□MDA*)

Grid Fretting Resistance Design
(Grid Design & Arrangement)

Debris filter
□Higher debris trapping capability□

TD □Theoretical Density
MDA□Mitsubishi Developed Alloy

Reactor Internals Design

US-APWR

Large volumetric core structure

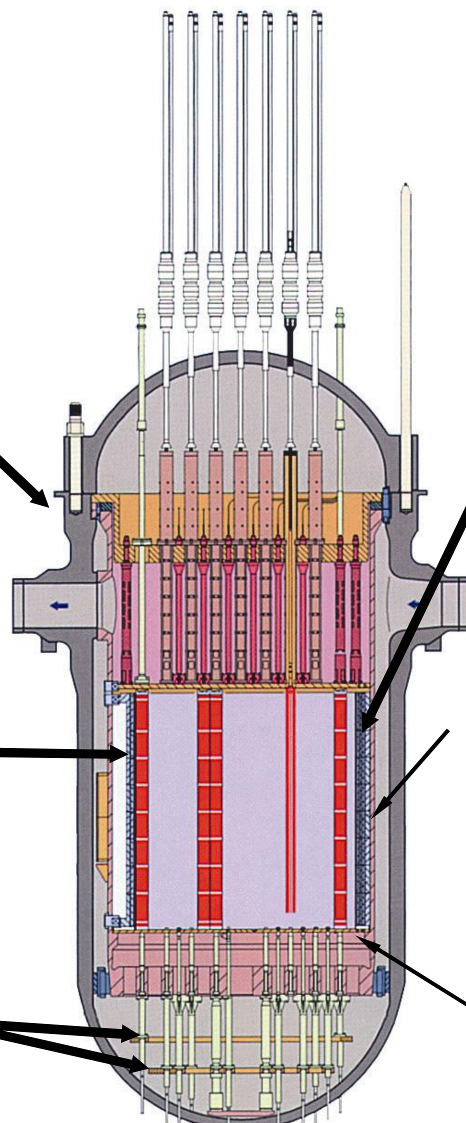
Large reactor internals
for large output

Enhanced reliability

Neutron Reflector
for simplified structure

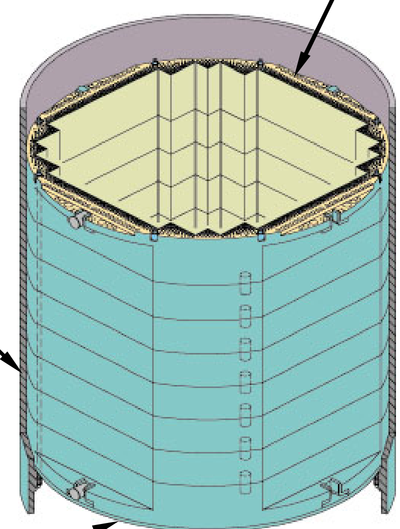
□Number of bolts□
2000 → 50)

Improved Tie Plate
for stabilized flow

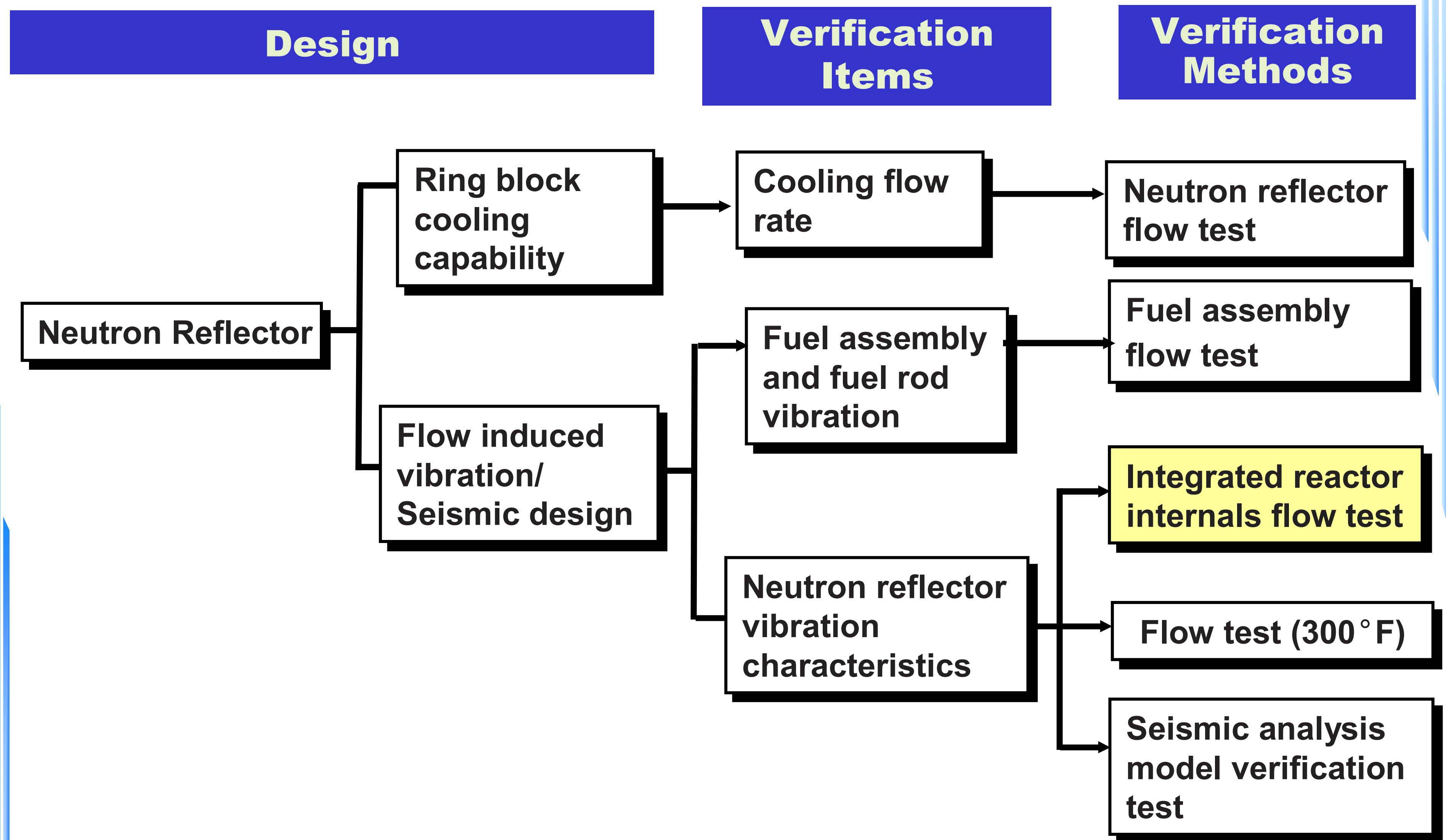


Enhanced performance

Neutron Reflector
for fuel cost reduction



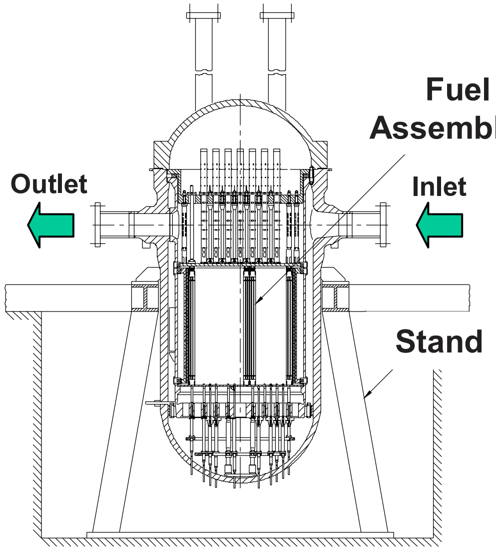
Verification of Neutron Reflector

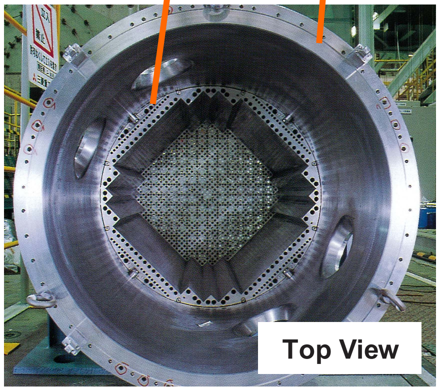


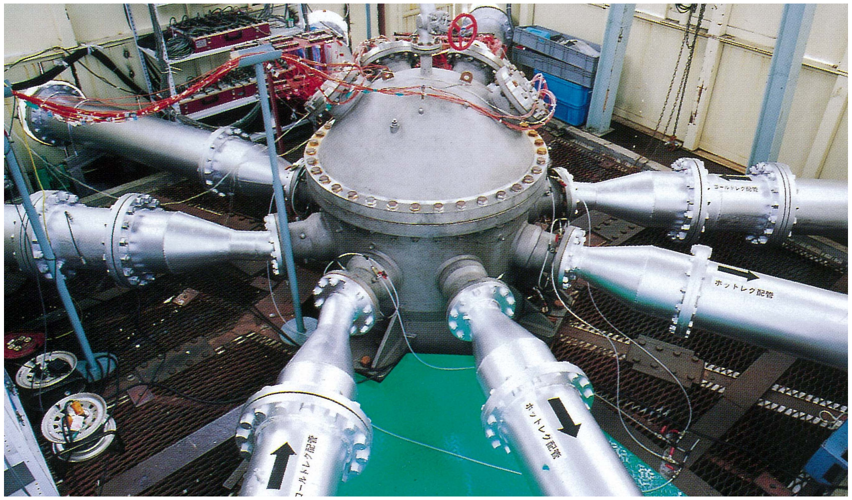
Verification of Neutron Reflector

Integrated Reactor Internals Flow Test

- **Test Model**
  - ✓1/5 scale of reactor vessel and internals
- **Test Conditions**
  - ✓Room temperature and Maximum 120% of mechanical design flow
- **Test Results**
  - ✓Flow-Induced vibrations are much smaller than high cycle fatigue limit.







Reactor Vessel / CRDM

Enhanced reliability

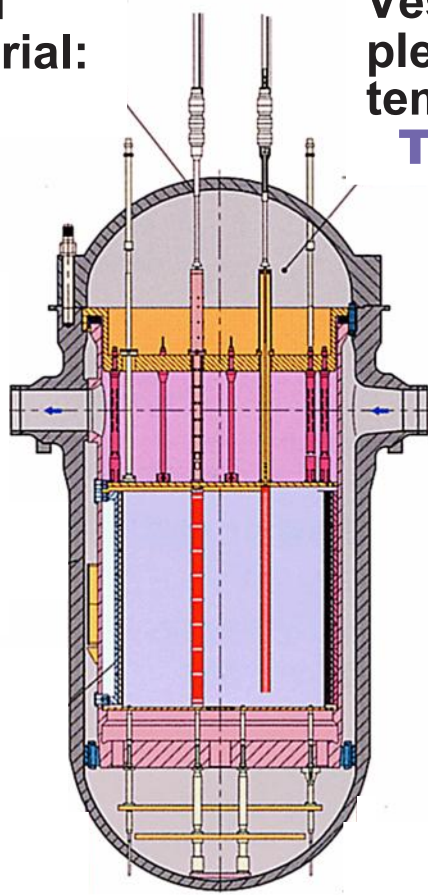
Reactor Vessel

Vessel head nozzle material:
Alloy 690

Vessel head plenum temperature:
Tcold

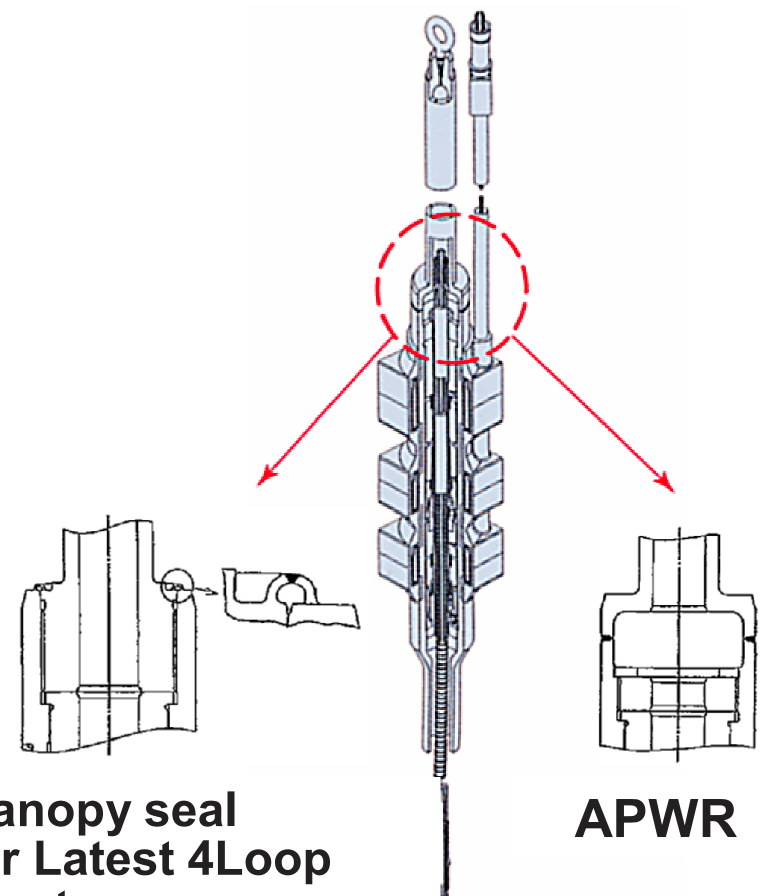
Reactor Vessel:
Reduction of weld lines using integrated forging

Neutron reflector:
Reduction of Vessel fluence (Reduce to 1/3)



CRDM housing

Elimination of canopy seal



Canopy seal for Latest 4Loop plant

APWR

Steam Generator

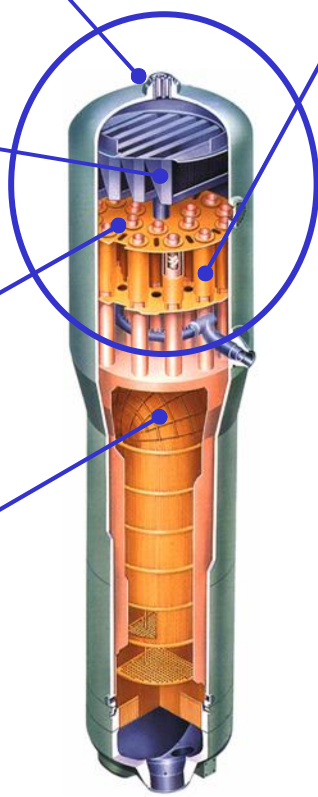
Improved water/steam separating performance

MCO (Moisture carry over) 0.01% or less in evaluation based on test

Secondary separator

Moisture 10%

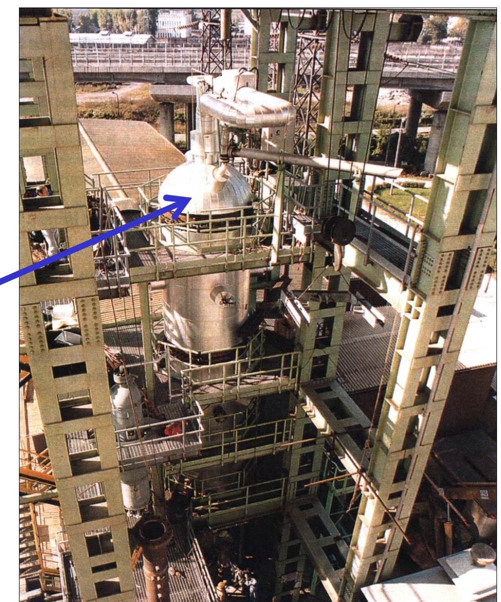
Inlet moisture 80%



Primary separator

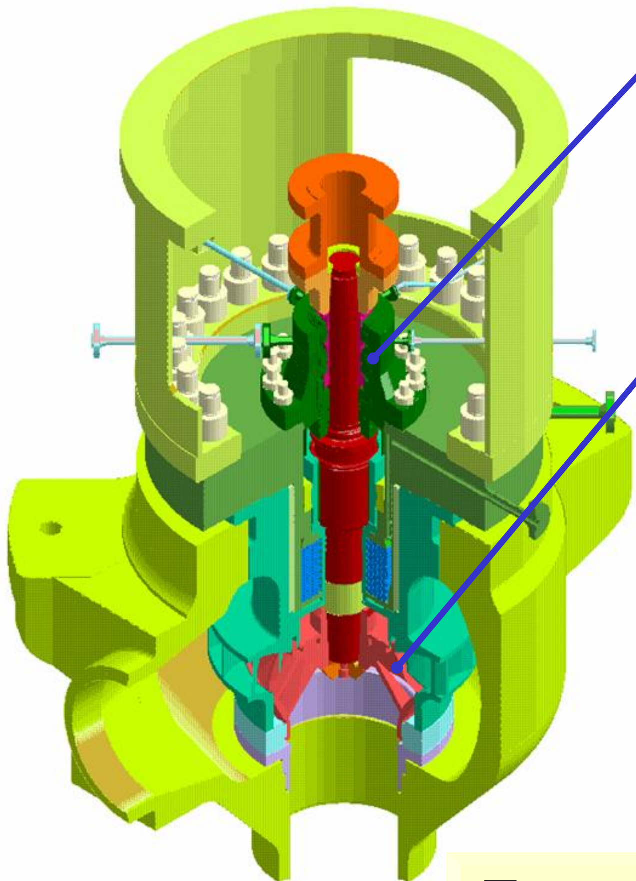
Verify with 1/1 scale mockup and actual pressure tester

1/1 scale mock up



High pressure and high temperature tester

Reactor Coolant Pump



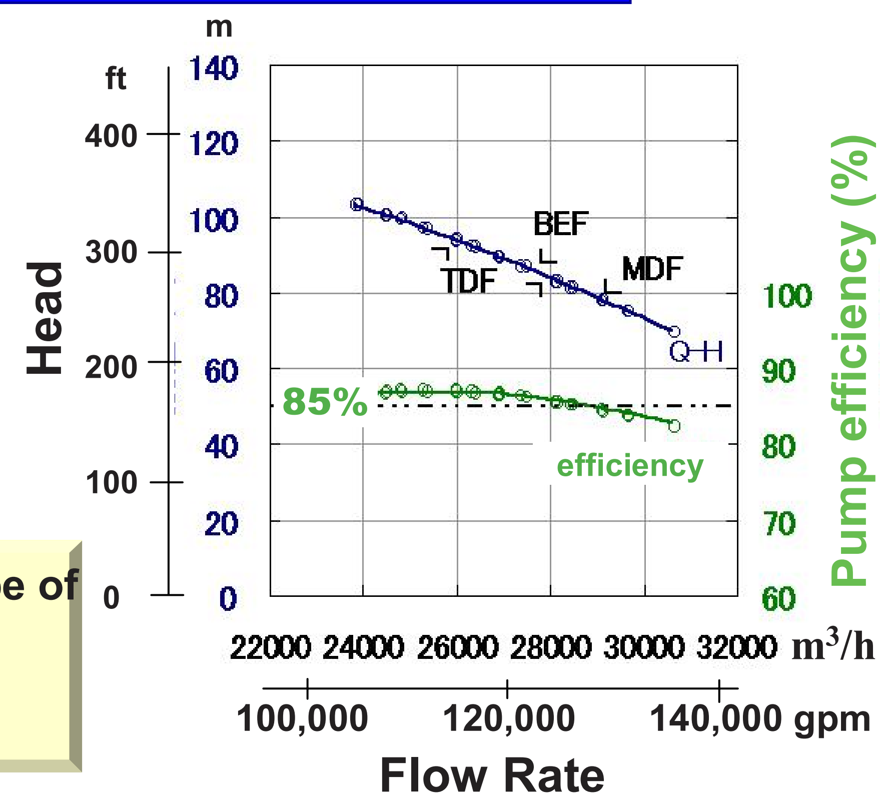
Model 100A

Advanced seals

Improved seal characteristics and durability
- No.1 seal :Enlarged ceramic type
- No.2,3 seal :Longer life mechanical type

Improved hydraulic performance

☐Improvement in shape of impeller and diffuser
☐Pump efficiency: Over 85%

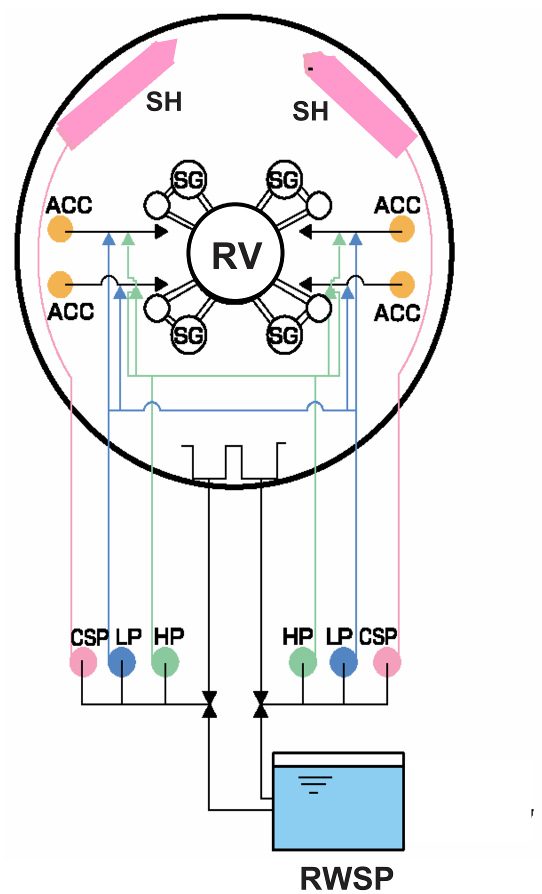


Safety Systems

- **Simplified and Reliable Safety Systems**
  - ✓ Safety systems with enhanced redundancy and independency
  - ✓ Reliable and simplified design is achievable by 50%×4 configuration for Safety Injection (HHSI*) Pumps in conjunction with adoption of Direct Vessel Injection (DVI) design   *High Head Safety Injection
- **Utilization of Advanced Accumulators**
  - ✓ Accumulators with function of Low Head Injection Pumps
- **In-Containment Refueling Water Storage Pit**
  - ✓ Improved reliability and safety by eliminating recirculation switching

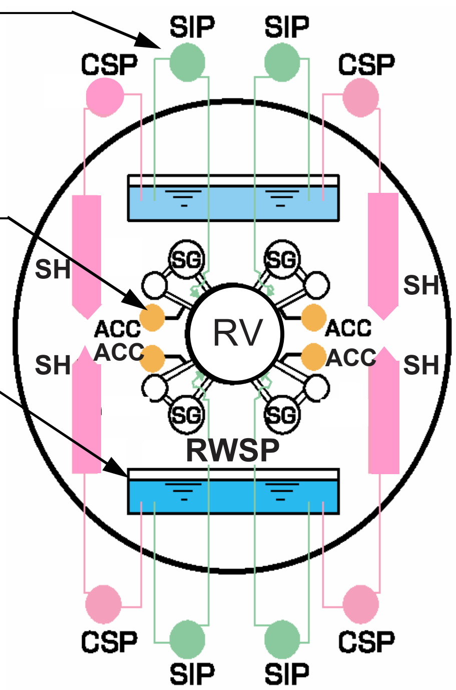
ECCS Configuration

Current 4 Loop PWR □2 train□



APWR □4 mechanical train□

- ◆4 train (DVI)
  → Higher Reliability
  Simplified Pipe Routing
- ◆Advanced Accumulator
  → Elimination of LP
- ◆In-containment RWSP
  → Higher Reliability



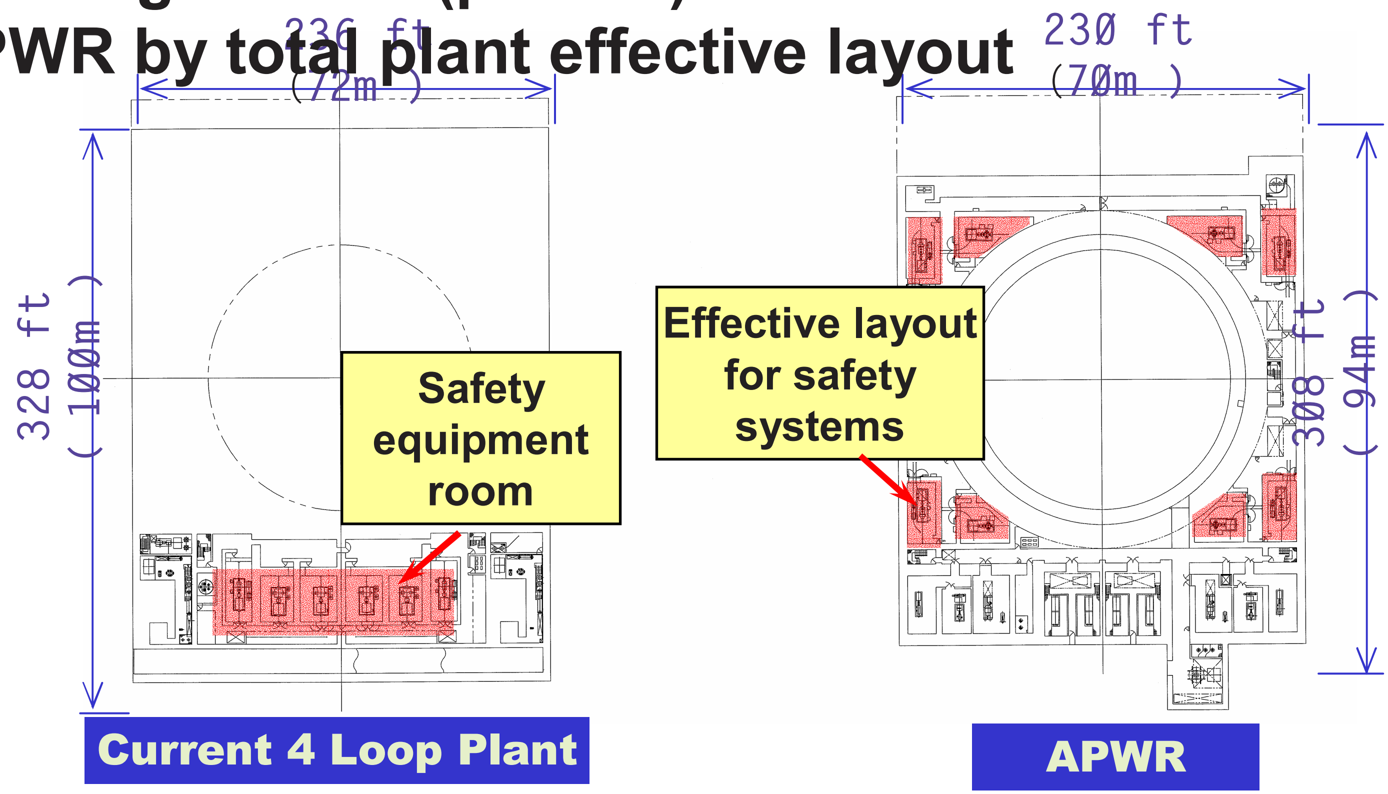
ACC	□Accumulator
HP	□High Head SIP
LP	□Low Head SIP
SIP	□Safety Injection Pump
CSP	□Containment Spray Pump
SH	□Spray Header
RV	□Reactor Vessel
RWSP	□Refueling Water Storage Pit

Comparison of Number of ECCS Equipments

	Current 4 Loop Plant	APWR
Accumulator	4 (conventional type)	4 (advanced type)
SI Pump - High Head Pump - Low Head Pump	 100%×2 100%×2 (used also as RHR)	 50%×4 □
CS Pump	100%×2	50%×4 (used also as RHR)

Simplified Layout for Safety Systems

- Lay down safety equipment at corner area of reactor building just close to RCS loops
  - ☐ Building volume / piping quantity can be reduced
- Building volume (per kW) was reduced about 20% in APWR by total plant effective layout

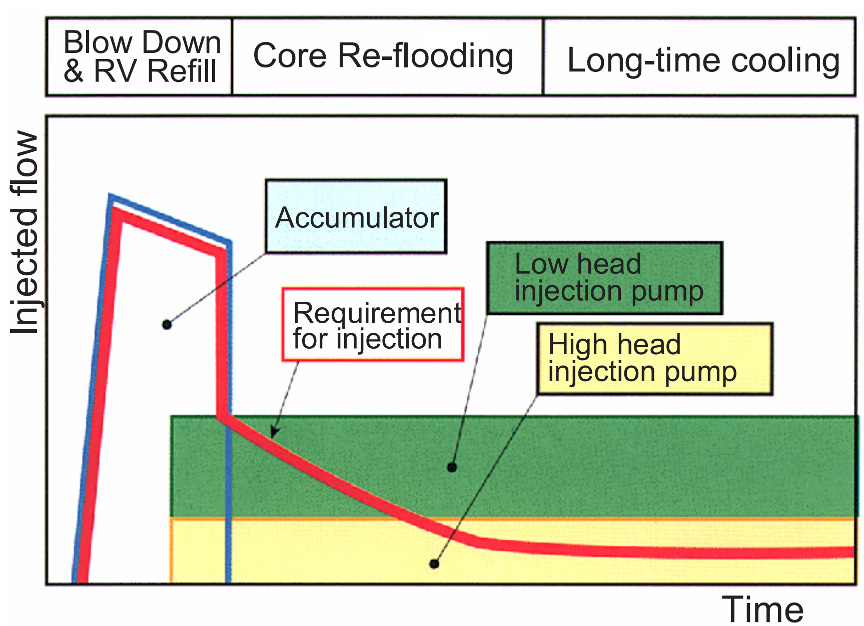


Advanced Accumulator

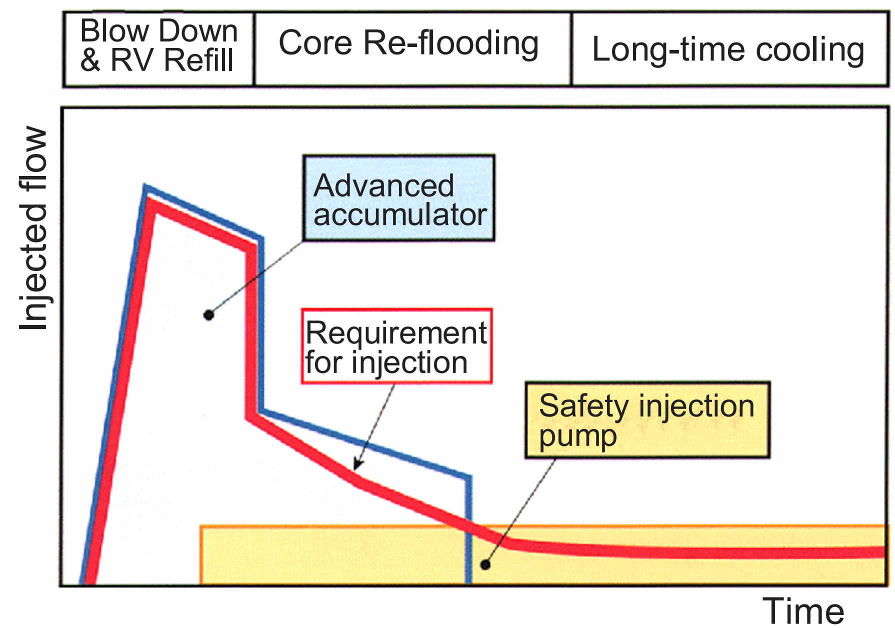
➢Automatic Switching of Injection Flow Rate by Flow Damper
➢Elimination of Low Head Injection Pumps
- ✓ Improvements of reliability
- ✓ Reduction of total capacity of safety injection pumps
- ✓ Substitution for RHR function by CS* Pumps/Coolers

□□Containment Spray

Current 4 Loop plant



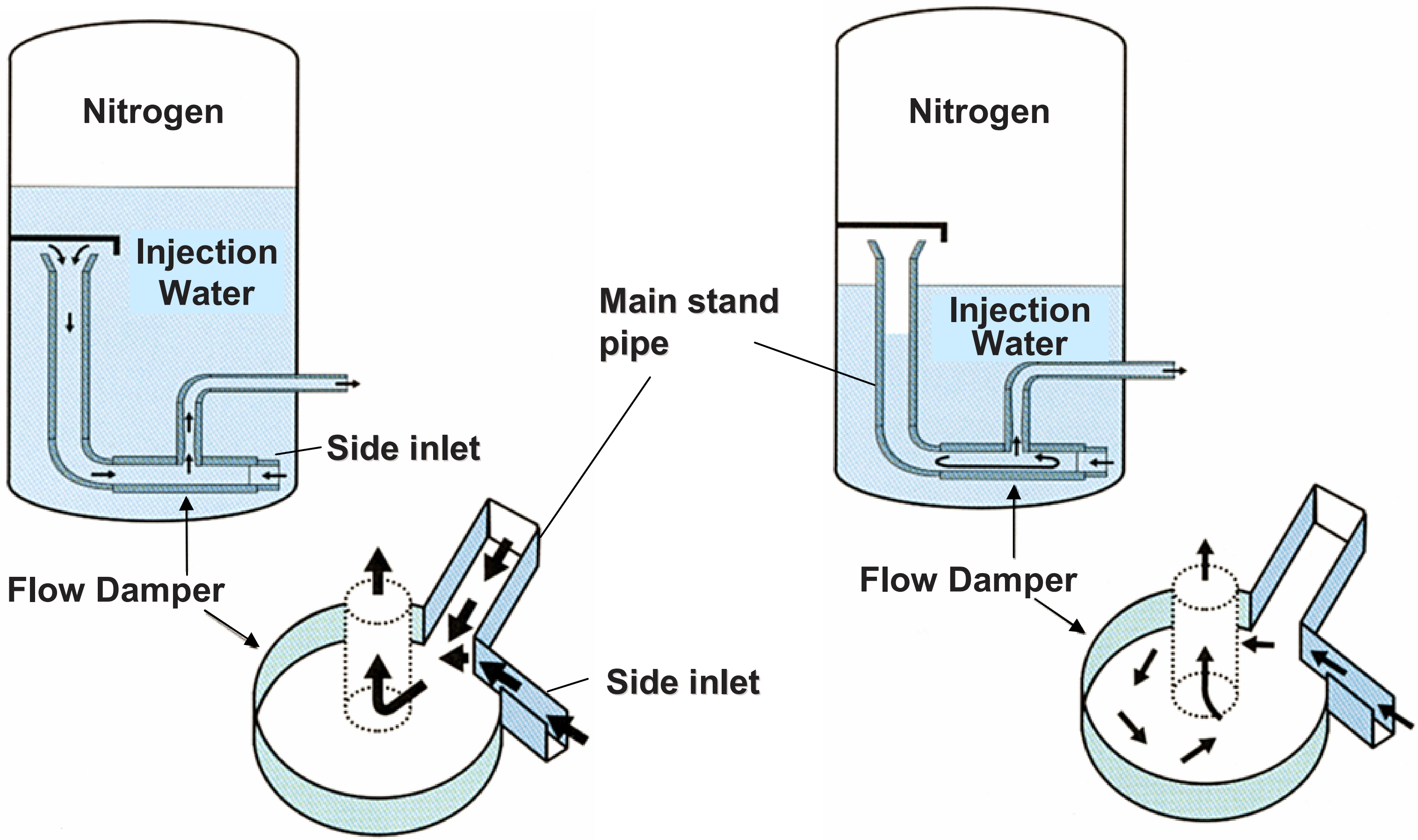
APWR



Mechanism of Advanced Accumulator

US-APWR

Flow damper passively switches the flow rate.



Large Flow Rate

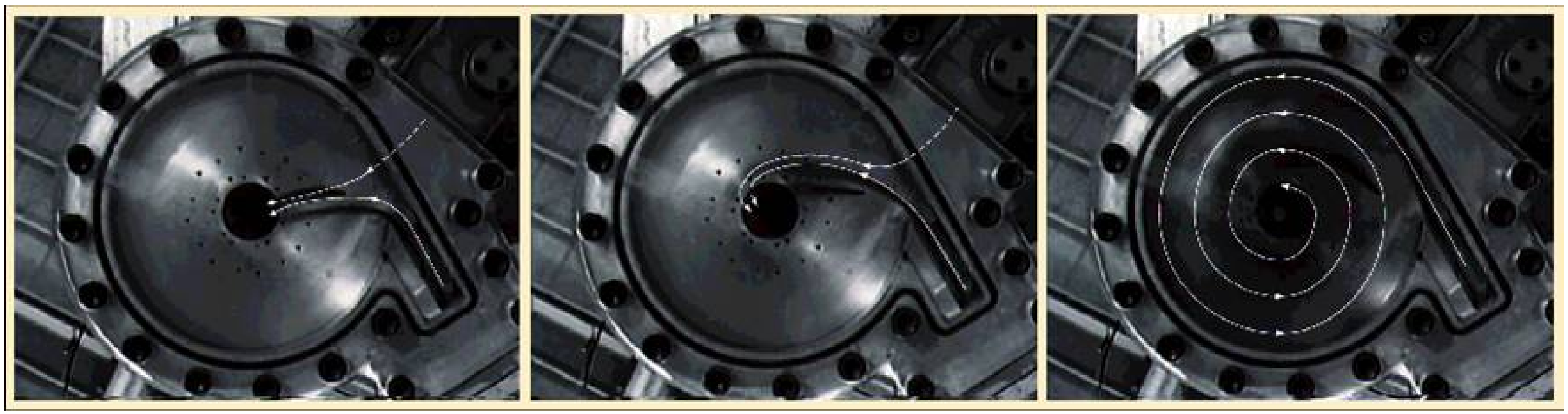
Reduced Flow Rate

Verification Test Results of Advanced Accumulator

US-APWR

Low Pressure Injection Test

- 1/5 Scale Flow Damper Model
- Low Pressure Test [Less than 116psi (0.8 MPa)]
- Focus Points
  - ✓ During large flow, no vortex flow is occurring.
  - ✓ During low flow, stable vortex flow is created, and flow rate decreases.



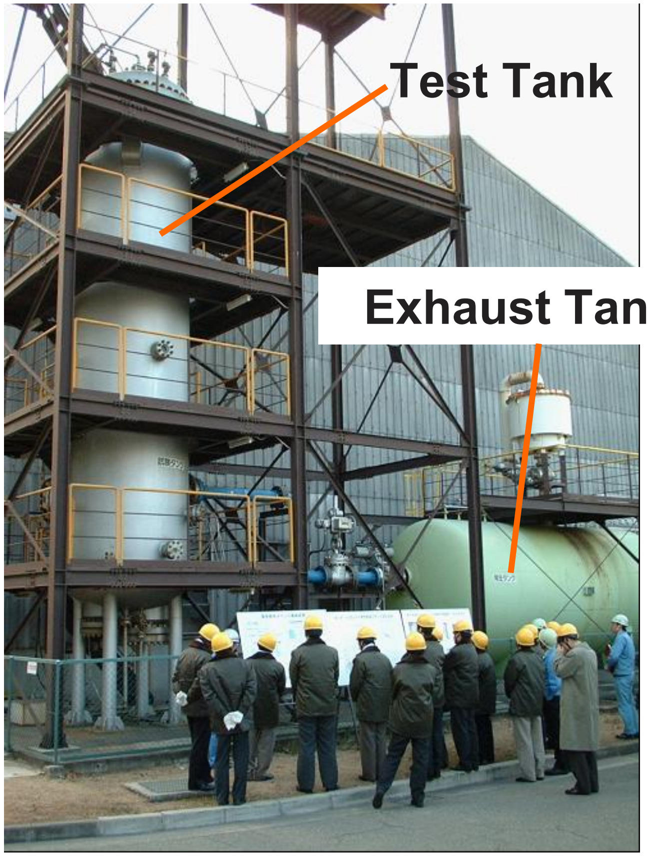
Large Flow | Flow Switching | Low Flow

Flow Pattern in Vortex Chamber

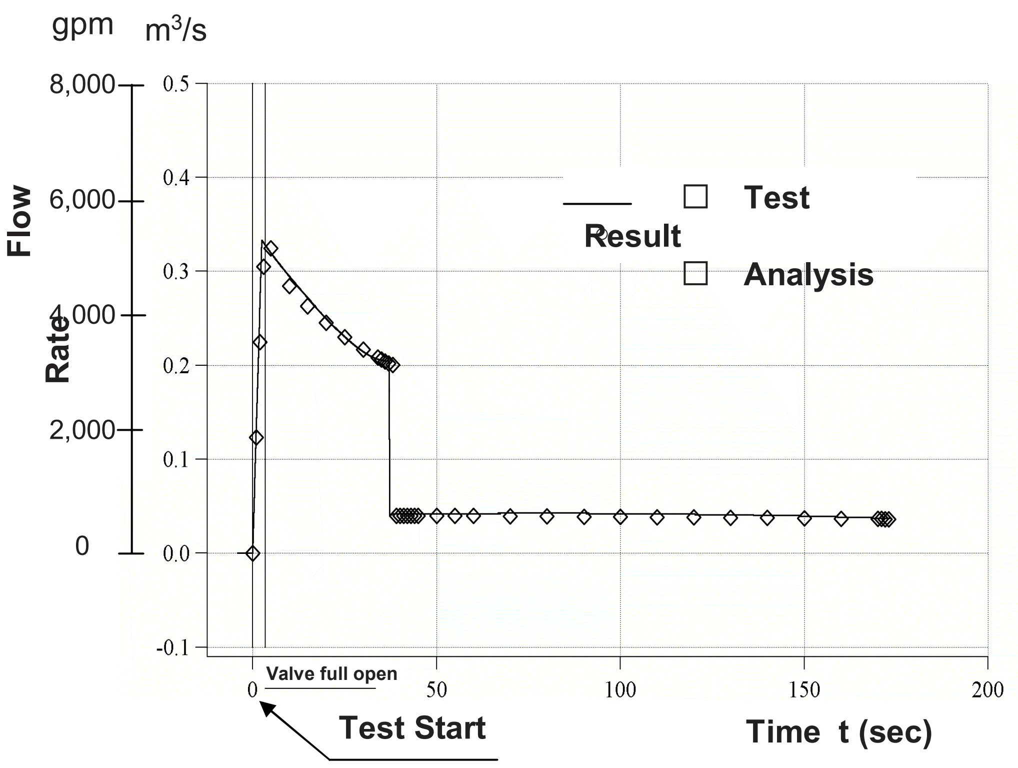
Verification Test Results of Advanced Accumulator

Test at Design N_2 Pressure

- 1/2 Scale Flow Damper Model
- Test Pressure:
  586 □757 psi (4.04□5.22MPa)



Test Apparatus



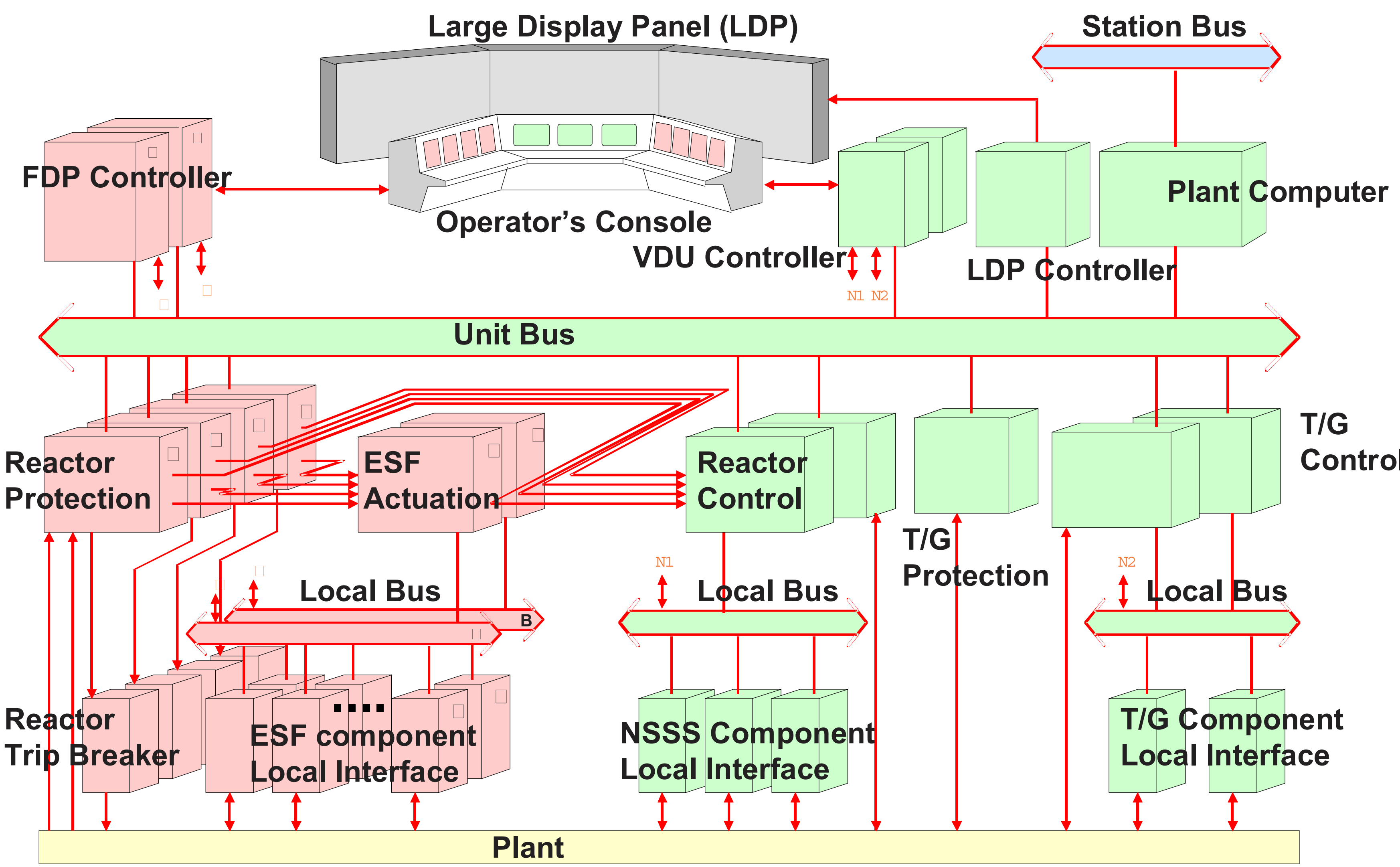
Injection Flow Rate

Instrumentation & Control

- ***Plant wide digital I&C system***
  - ✓ Computerized Control Room (Advanced Control Room)
  - ✓ Digital Safety System
  - ✓ Integrated Control and Monitoring Network
- ***Dedicated nuclear design and development process***
  - ✓ Simplified and Traceable design
  - ✓ Compliance with major design criteria and standards
  - ✓ Intensive verification
- ***Various implementation experience***
  - ✓ Step-by-step approach (Non-safety to safety)
  - ✓ Plant construction and Operating plant modernization

All the efforts have been integrated into APWR I&C design

I & C System Architecture



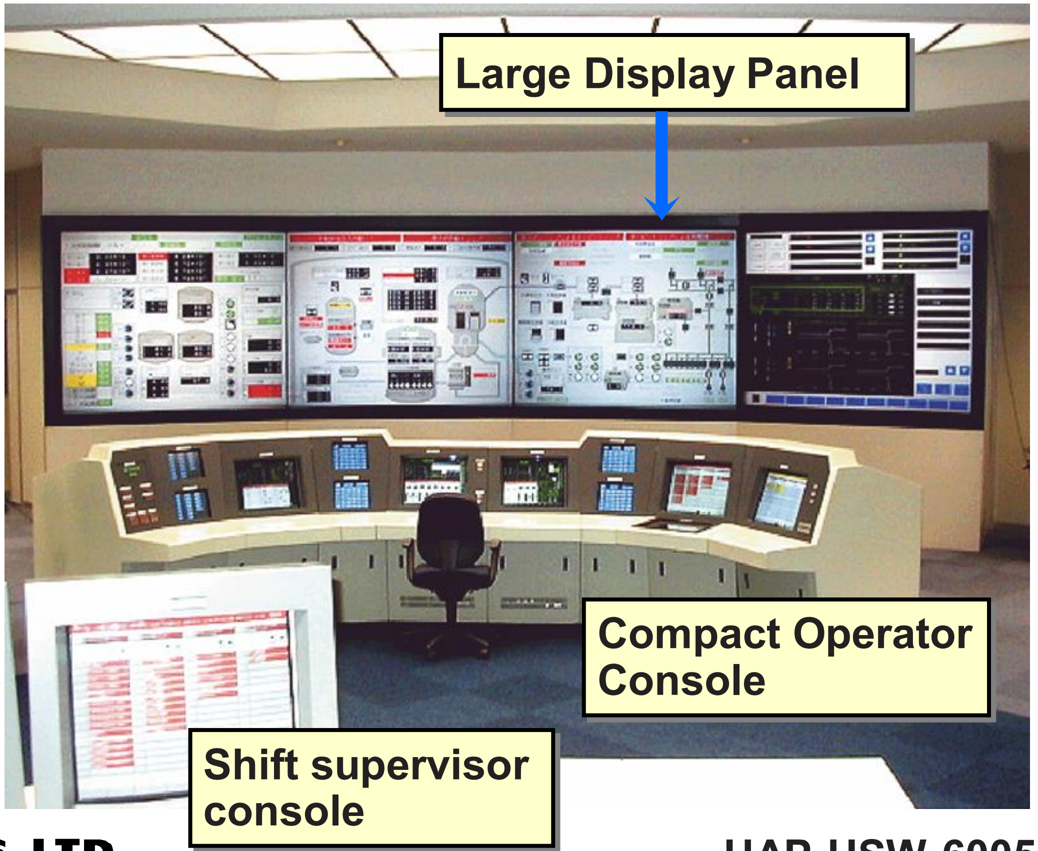
Advanced Control Room

1970's Improvement after TMI

1980's Systematic Human-Factor approach

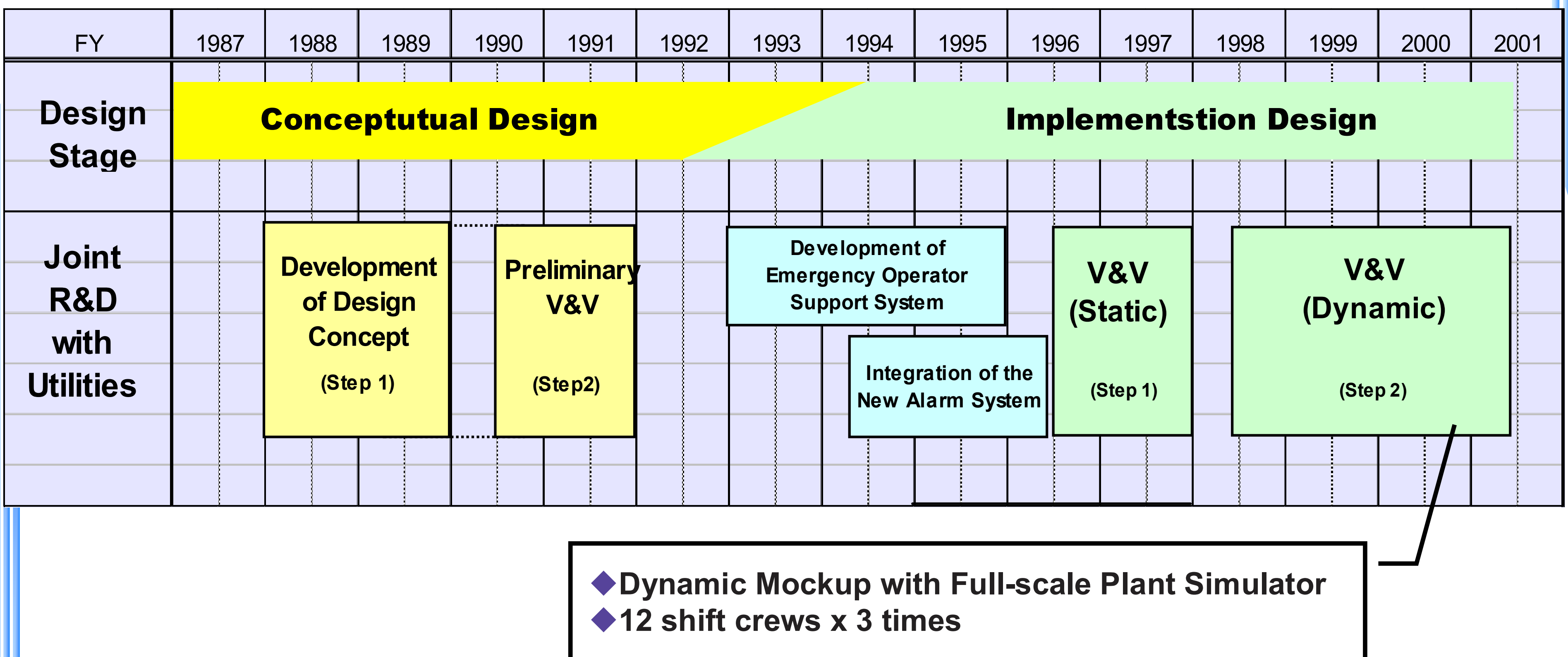
2000's Human centered design with new technology

- Easy recognition of plant overview for all of shift operator crew members
- Smooth operations realized by concentrating monitoring and operation functions in a compact console



History and Development Process of ACR

- Step by step approach for design process and V&V
- V&V by plant operators using full-scale simulator



ACR: Advanced Control Room

Summary of APWR New Design Features

- APWR integrates all operation experiences and technology improvements of Japanese PWRs.
- APWR achieves high reliability by employing proven technologies and "carefully verified" advanced technologies.
- APWR achieves better economy, safety, and operation/maintenance ability by applying state-of-the-art technologies.

3.3 Conclusion of US-APWR Overview

Main Plant Parameters of US-APWR

	APWR	US-APWR
Electric Output	1,538 MWe	**1,700 MWe Class**
Core Thermal Output	4,451 MWt	4,451 MWt
Core	12 ft Fuel 257Assem.	**14 ft Fuel** 257 Assem.
SG Heat Transfer Area per SG	70,000□□²	**91,500□□**
Thermal Design Flow rate per loop	113,000 GPM	112,000 GPM
Turbine	54 inch blades	**70 inch class blades**
Containment Vessel	PCCV	PCCV
Safety Systems	Electrical 2 trains Mechanical 4 trains	**Electrical 4 trains** Mechanical 4 trains
	HHSI× 4 Advanced Accumulator x 4 Elimination of LHSI	HHSI ×4 Advanced Accumulator x 4 Elimination of LHSI
□□□	Full Digital	Full Digital

Conclusion of US-APWR Overview

- Based on the current APWR technologies, Mitsubishi offers an international standard APWR, the US-APWR, for near-term deployment in U.S. and other areas.
- US-APWR is being engineered based on proven and reliable technologies.
  - ✓ Improved plant efficiency incorporating improved steam generators and turbine system
  - ✓ Reduced fuel cycle cost and improved operational flexibilities by low power density core with 14 ft. fuel assemblies.
  - ✓ Minor modifications of APWR for U.S. utility requirements.

4. Future Plan

Pre-Application Review Meeting Plan

Meeting Subject	Date
• Mitsubishi Nuclear Activities • US-APWR Overview	July 2006
• US-APWR Design Features* • Safety Fluid System (ECCS) • Finalize Future Schedule of Report Submittals	September 2006
• Safety design basis of Reactor Protection & ESF Actuation system • I & C System Architecture (Safety System)	November 2006
• Other Safety Fluid Systems	January 2007
• Fuel and Core Design methodology	April 2007

** US-APWR Design Description Report is planned to be submitted in September, 2006 to support the Pre-application review.*

Pre Application Review Meeting Plan

Meeting Subject	Date
• I & C (Human System Interface, Reactor Instrumentation) • Electrical System	June 2007
• Plant Layout, Fire Protection and Train Separation, Steel & Concrete Structure, Containment Vessel	September 2007
• Safety Analysis Methodology (LOCA, Non LOCA) • Radiation Dose Analytical Methodology	December 2007
• Severe Accident Methodology • Probabilistic Risk Assessment Methodology	February 2008

Design Certification Application Plan

- The Application of US-APWR Design Certification will be submitted by the end of March, 2008.