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1879-3

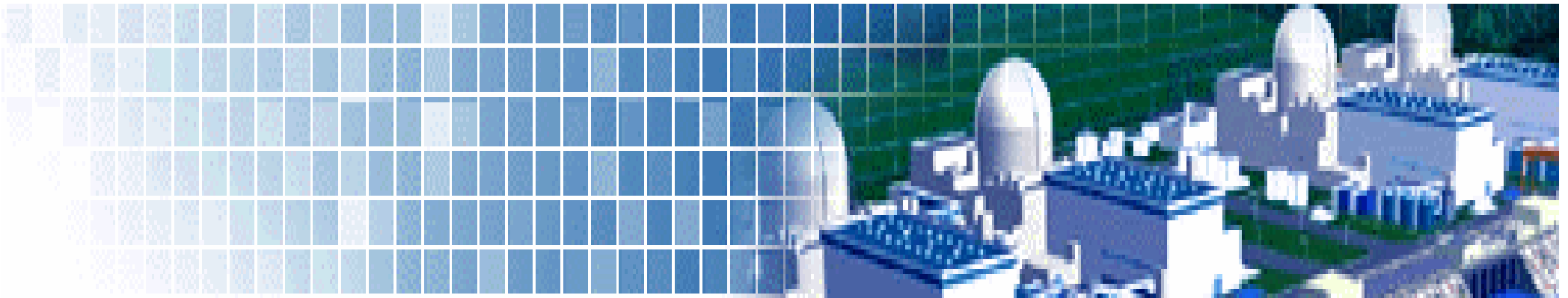
Nuclear Power Plant Simulators for Education

29 October - 9 November, 2007

lecture notes

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Austria*

Evolution of Full-Scope Simulators Development-- Korean experience



Workshop on NPP Simulators for Education

2 November, 2007

Miramare- Trieste, Italy

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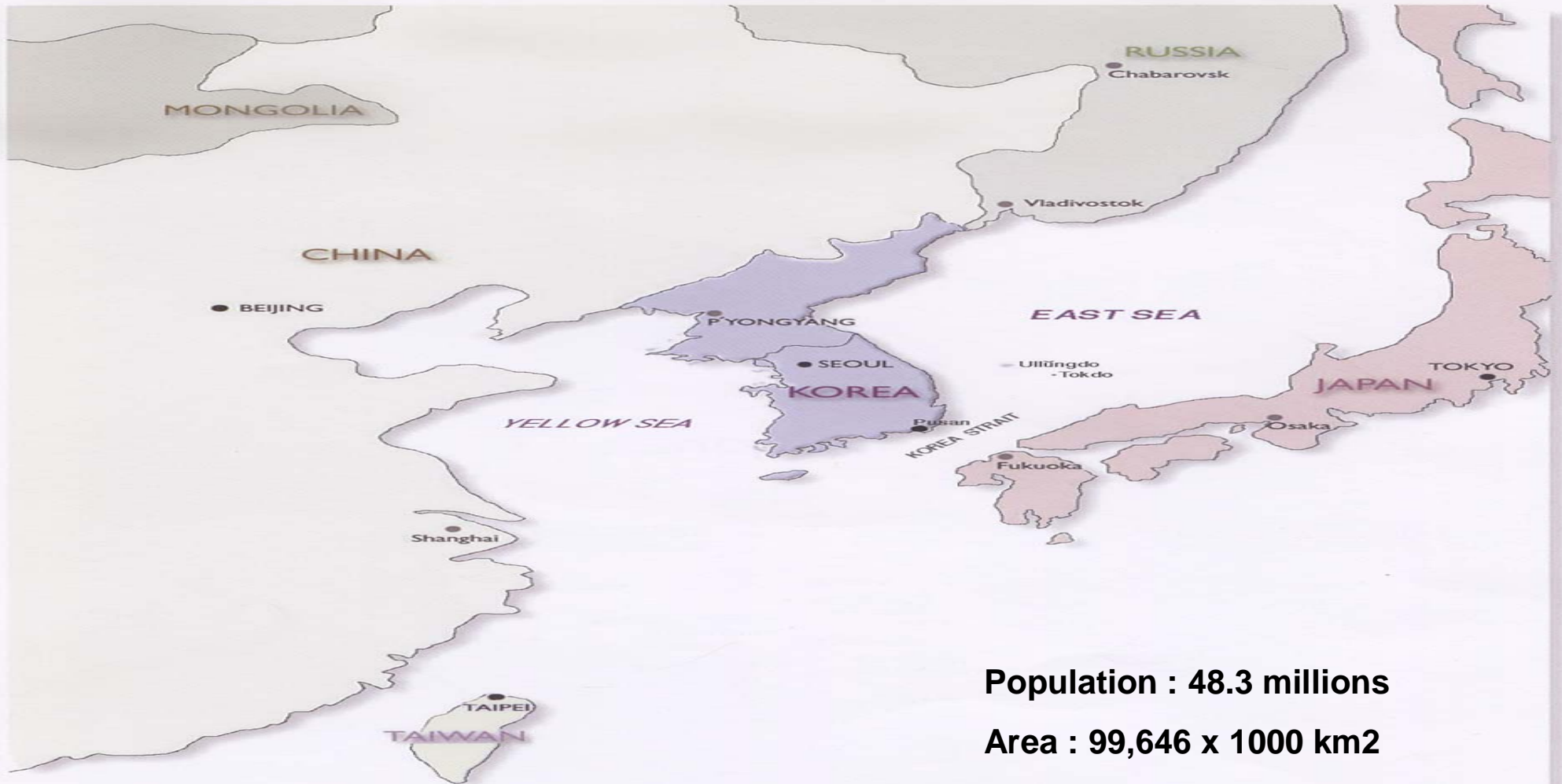
- **Status, Development History**

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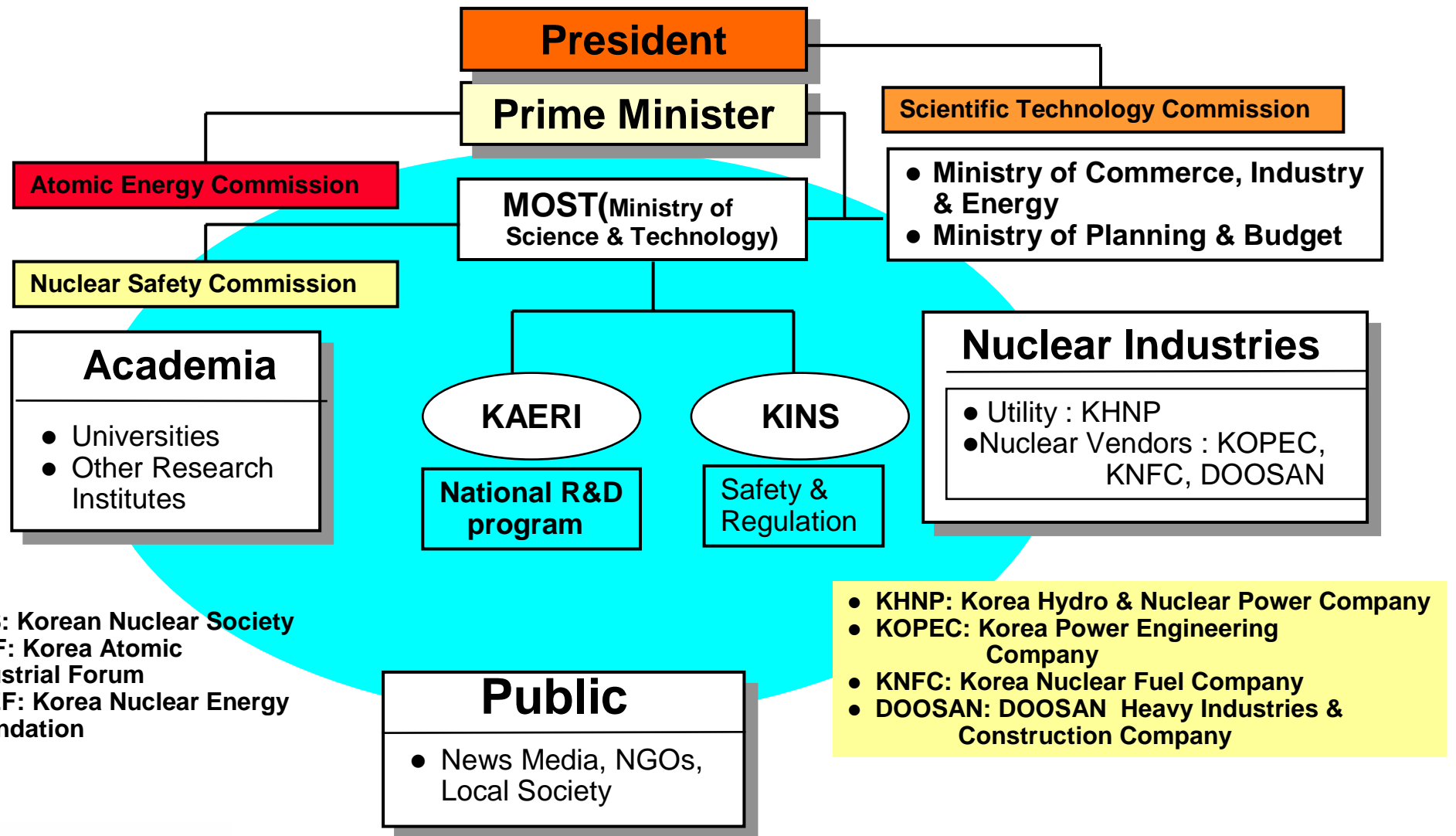
Geological location



Brief History of Nuclear Power in Korea

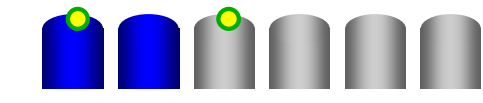
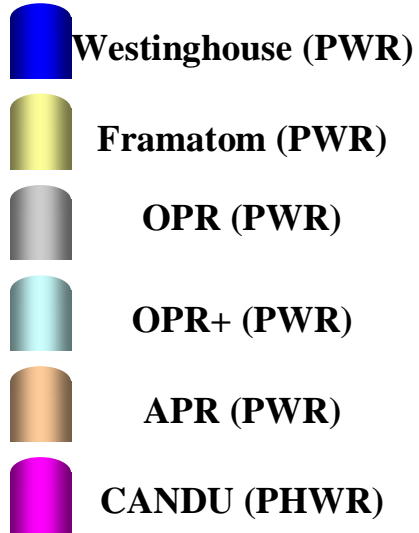
- 1957 Joining the IAEA (International Atomic Energy Agency)
- 1958 Promulgation of Atomic Energy Law
- 1959 Start construction of 1st Research Reactor (TRIGA Mark-II) (completed in 1962)
- 1968 Set-up basic plan for introduction of 1st NPP
- 1969 Set-up construction plan for 1st NPP, Kori #1 (PWR 587MWe)
- 1971 Start construction of 1st NPP, Kori #1
- 1978 Commercial operation of 1st NPP, Kori #1
- 1983 Commercial operation of 2nd NPP(Kori #2) and 3rd NPP (Wolsong #1)
- 1995 Exceed 500 Billion KWh of Nuclear Power Generation (9 NPPs in Operation)
- 1997 Exceed 10,000 MW of Nuclear Installed Capacity (12 NPPs in Operation)
- 2001 Establish “ Basic Plan for Restructuring of the Electricity Supply Industry”
- 2005 20 units in Operation (The installed capacity is 17,716 Mwe)

Korea's Nuclear Related Organizations

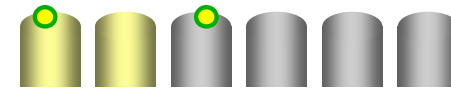


NPPs & Operator Training Centers in Korea

- 20 NPPs - operating
- 8 NPPs – constructing or planning
- 4 Nuclear Power Training Centers
- 7 NPP FSSs



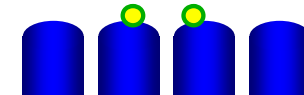
Yonggwang-1,2,3,4,5,6



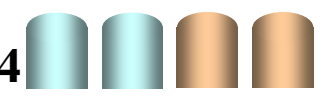
Ulchin-1,2,3,4,5,6(PWR)



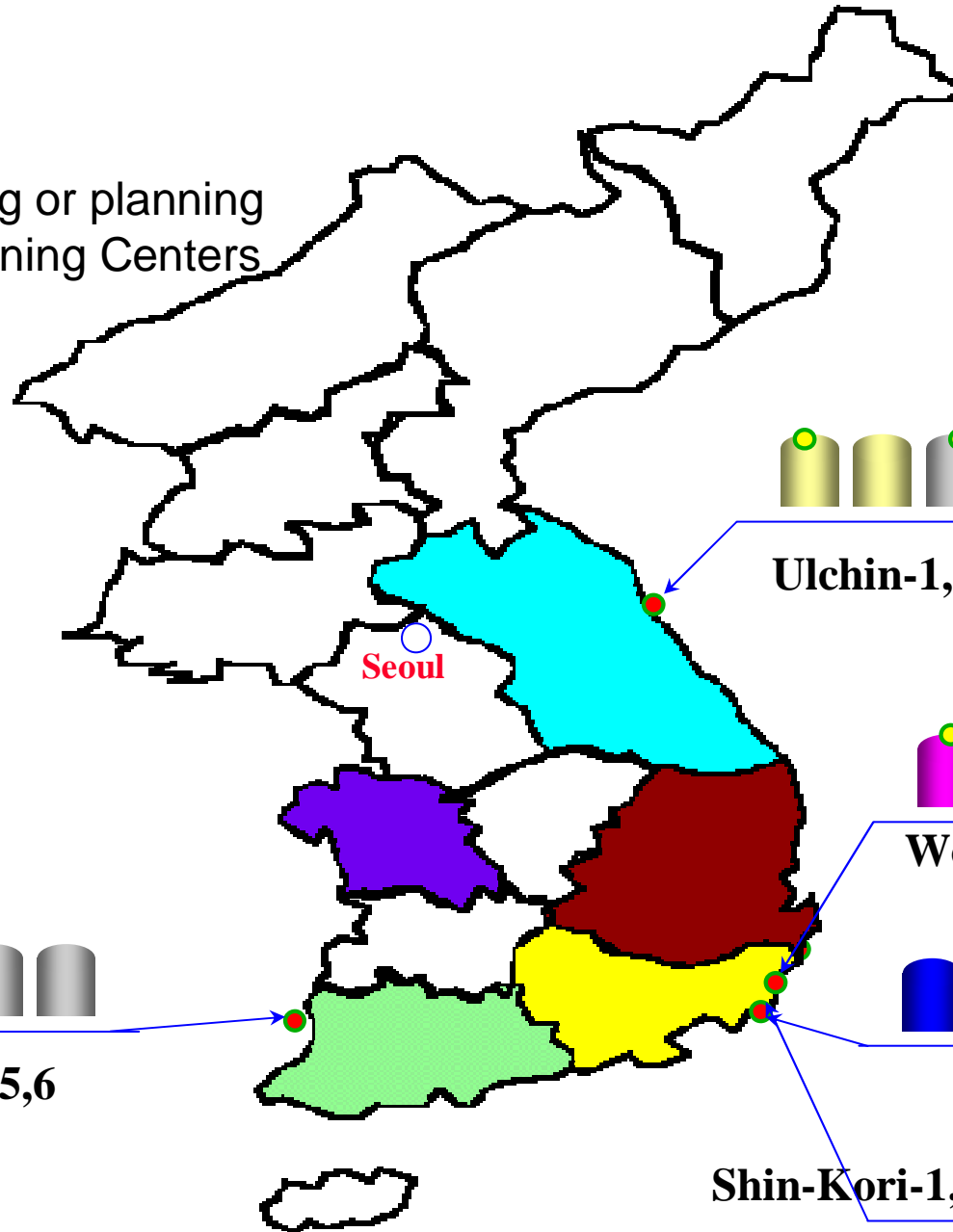
Wolsong-1,2,3,4(PHWR)



Kori-1,2,3,4



Shin-Kori-1,2,3,4



Nuclear Power Plants in Operation

■ 20 units, 17,716 MWe

Plant		Reactor Type	Capacity (MW)	NSSS Supplier	Plant A/E	Commercial Operation
Kori	#1	PWR	650	W/H	Gilbert	'78.04
	#2	PWR	587	W/H	Gilbert	'83.07
	#3	PWR	950	W/H	Bechtel/KOPEC	'85.09
	#4	PWR	950	W/H	Bechtel/KOPEC	'86.04
Wolsong	#1	PHWR	679	AECL	AECL	'83.04
	#2	PHWR	700	AECL/DOOSAN	AECL/KOPEC	'97.06
	#3	PHWR	700	AECL/DOOSAN	AECL/KOPEC	'98.06
	#4	PHWR	700	AECL/DOOSAN	AECL/KOPEC	'99.09
Yonggwang	#1	PWR	950	W/H	Bechtel/KOPEC	'86.08
	#2	PWR	950	W/H	Bechtel/KOPEC	'87.06
	#3	PWR	1,000	DOOSAN	KOPEC	'95.03
	#4	PWR	1,000	DOOSAN	KOPEC	'96.01
	#5	PWR	1,000	DOOSAN	KOPEC	'02.05
	#6	PWR	1,000	DOOSAN	KOPEC	'02.12
Ulchin	#1	PWR	950	Framatome	Framatome	'88.09
	#2	PWR	950	Framatome	Framatome	'89.09
	#3	PWR	1,000	DOOSAN	KOPEC	'98.08
	#4	PWR	1,000	DOOSAN	KOPEC	'99.12
	#5	PWR	1,000	DOOSAN	KOPEC	'04.07
	#6	PWR	1,000	DOOSAN	KOPEC	'05.04

NSSS : Nuclear Steam Supply System, A/E : Architect Engineering

NPPs Under Construction / Preparation/Planning

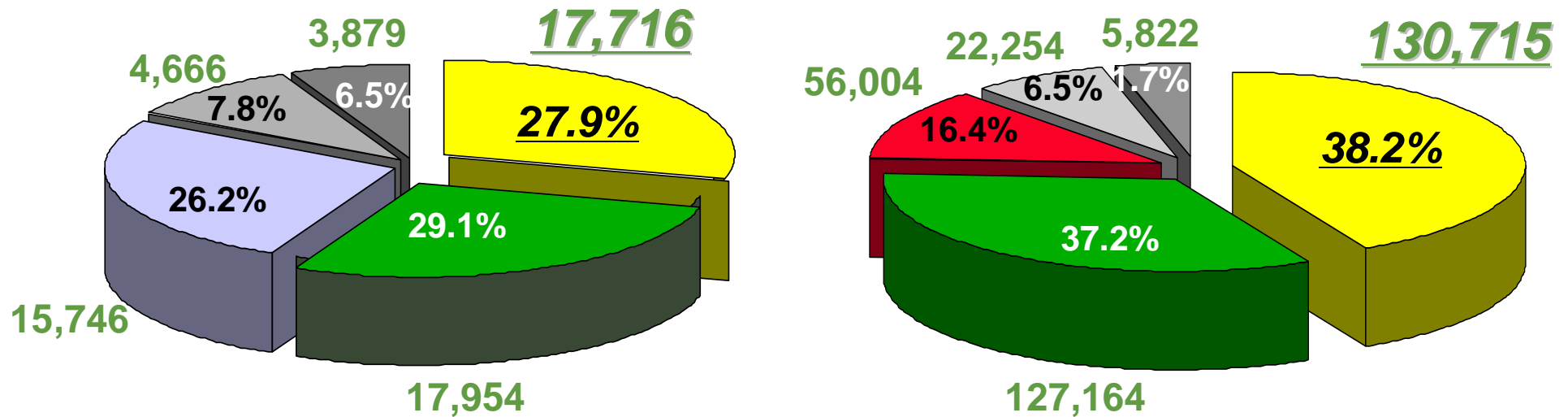
■ 8 Units : 9,600 MWe

Project	Reactor Type	Capacity (MW)	Plant Type	Commercial Operation*	
Shin-Kori	#1	PWR	1000	OPR1000+	Dec. 2010
	#2	PWR	1000	OPR1000+	Dec. 2011
	#3	PWR	1400	APR1400	Jul. 2012
	#4	PWR	1400	APR1400	Jul. 2013
Shin-Wolsong	#1	PWR	1000	OPR1000+	Oct. 2011
	#2	PWR	1000	OPR1000+	Oct. 2012
Shin-Ulchin	#1	PWR	1400	APR1400	June. 2014
	#2	PWR	1400	APR1400	June. 2015

* The target dates for commercial operation are being adjusted project due to the local governments' construction work licensing process.

Status of Electric Power

Korea is the 6th largest nuclear power country in the world.
 KHNP is the world's 5th largest nuclear power company.



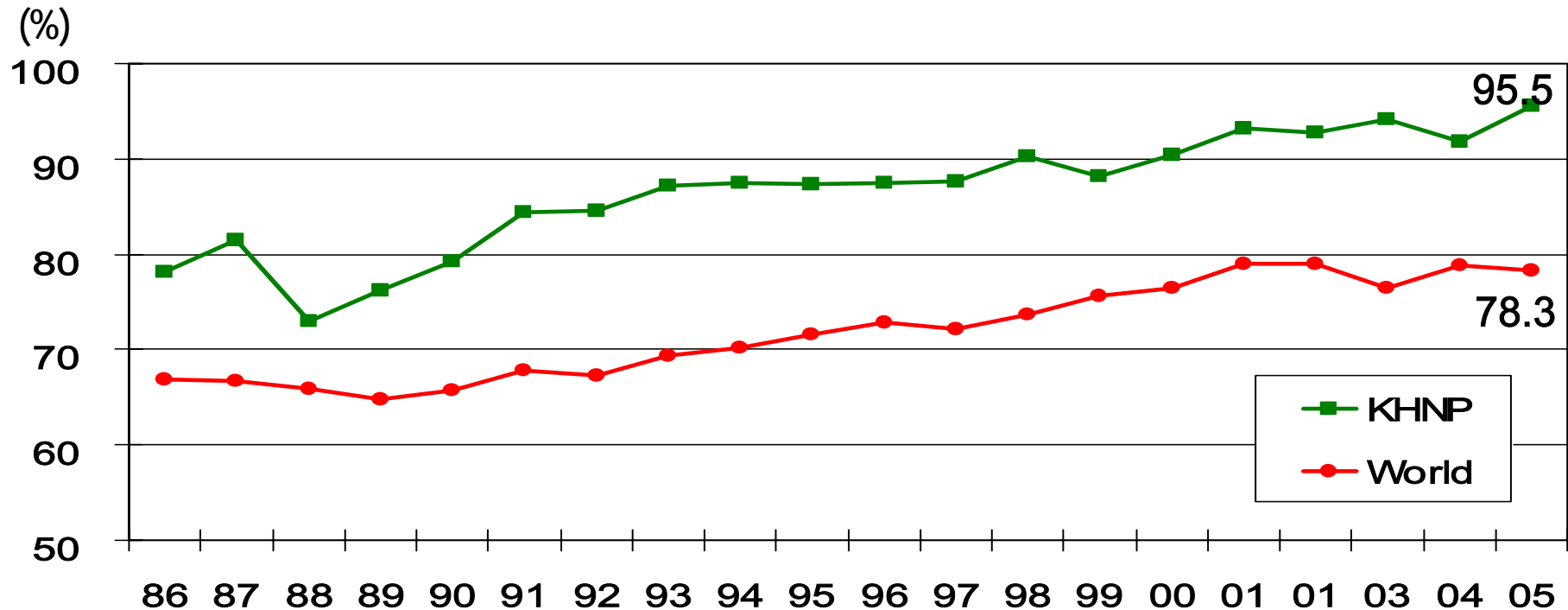
Installed Capacity: 59,961 MW

Generation: 341,959 GWh



Operational Performance

□ Trend of Average Capacity Factors



KHNP	78.1	81.5	73.0	76.2	79.3	84.4	84.5	87.2	87.4	87.3	87.5	87.6	90.2	88.2	90.4	93.2	92.7	94.2	91.8	95.5
World	66.9	66.7	65.9	64.8	65.7	67.8	67.3	69.4	70.2	71.6	72.9	72.1	73.7	75.6	76.4	78.9	78.9	76.5	78.8	79.3

Korean reactors have shown excellent performance !

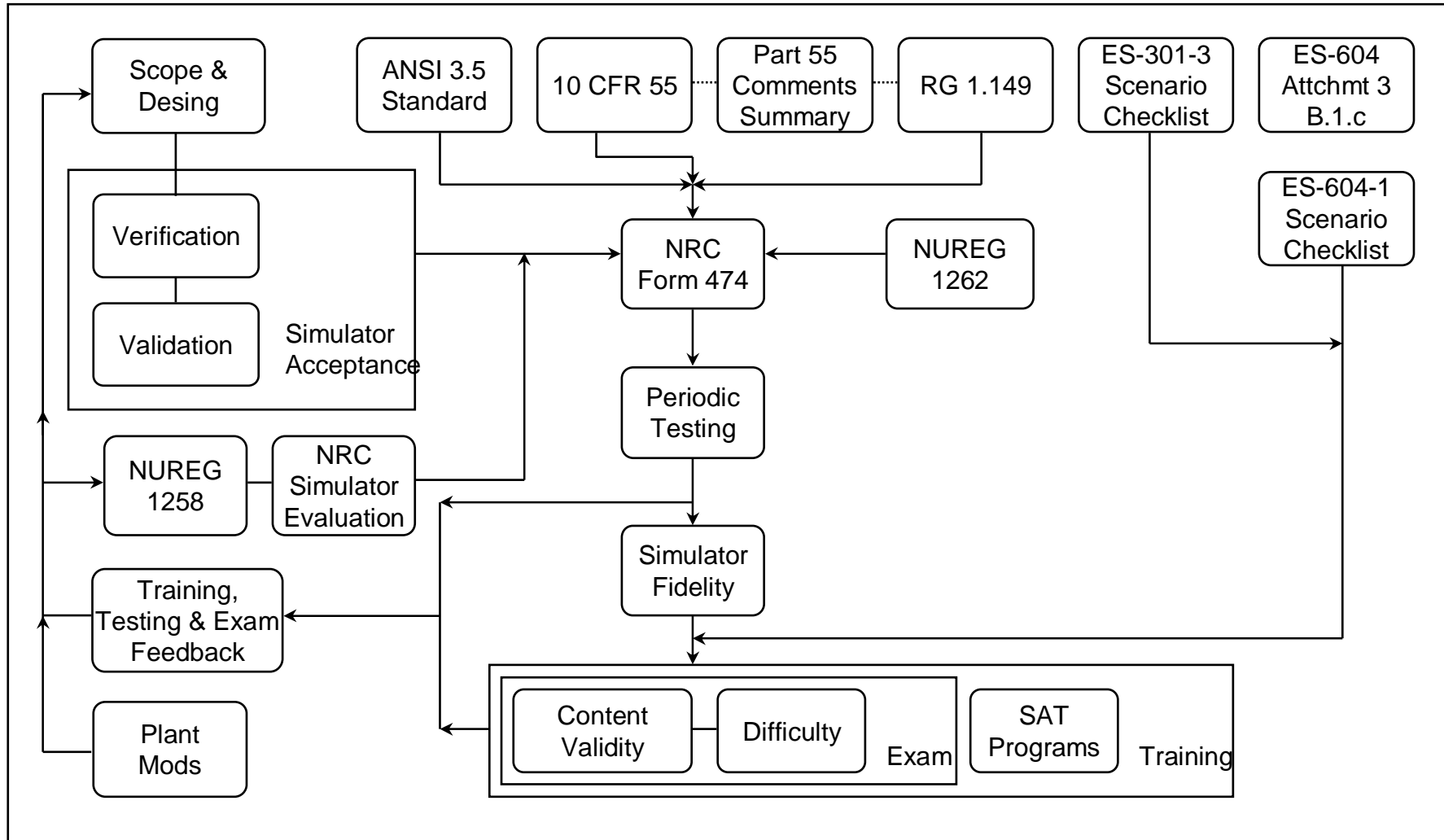
II. Nuclear power plant simulation

Full scope simulator of nuclear power plant

- **Standard Requirement: ANSI/ANS3.5-1998**
 - **Nuclear Power Plant Simulators for Use in Operator Training and Examination**



Simulator Regulatory Relationships



Role of Full Scope Simulator Training

- **Maintain the required level of competence of operations personnel as defined for the initial training**
- **Train all significant modifications of plant operation caused by improvements and alterations of the Plant or Procedure**
- **Emphasize on Emergency Procedures in the handling of unforeseen Events**

Types of Simulator and Uses

- Full-scope simulator
 - A replica control room and simulates the NSSS and the BOP system for a reference plant
- Part-task simulator
 - Designed for training on a specific subset of plant operation or on a special phenomenon
 - ex) Thermo hydraulic simulators and simulators for training in relation to steam generator tube rupture
- Basic principle simulator
 - Illustrates general concepts, demonstrating and displaying the fundamental physical processes of the plant.
 - ex) Based on PCs and Specific system modeling (RCS, etc.)

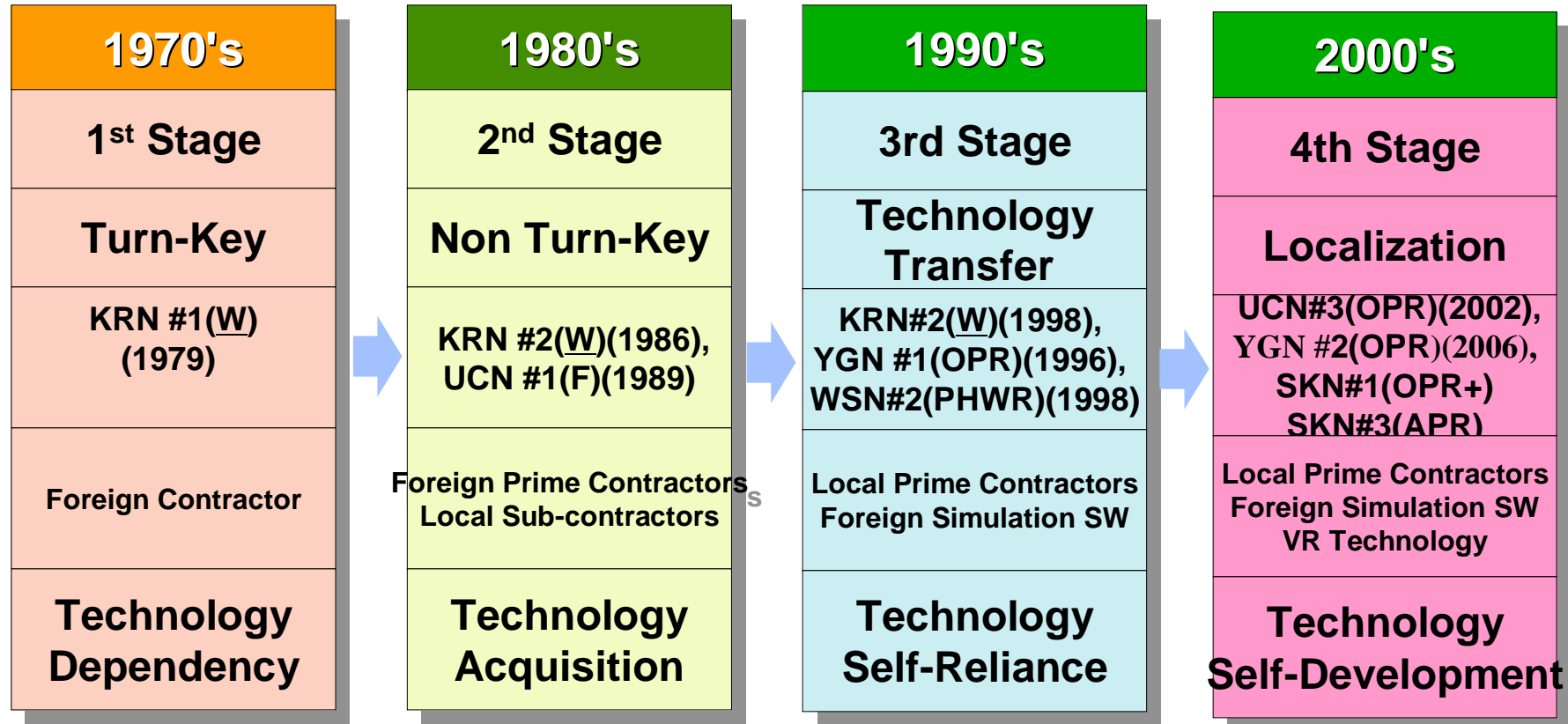
II. Evolution of Simulator Development

Status of Full Scope Simulator in Korea

Location		Reference Plant	Operation Date	Manufacturer	Application	Remarks
KOR T/C	#1	KOR #2	Nov. '98	Samsung	KOR #1&2	PWR 650MWe
	#2	KOR #3	Dec. '86	W/H(USA)	KOR #3&4	PWR 950MWe
UCN T/C	#1	UCN #1	Jan. '89	Thomson- CSF(France)	UCN #1&2	PWR 950MWe
	#2	UCN #3	Mar. '02	Samsung	UCN #3,4,5,6	PWR 1000MWe
YGN T/C	#1	YGN#3	Apr. '96	Samsung	YGN #3,4,5,6	PWR 1000MWe
	#2	YGN#1	Sept. '06	Samsung	YGN #1,2	PWR 950MWe
WSN T/C		WSN #2	Dec. '98	CAE(Canada)	WSN #1,2,3,4	PHWR 700MWe

- ◆ Originally, KOR #1 Simulator was the copy of Surry Simulator, in 1979, but KHNP has changed into Reference Plant of Kori #2 manufactured by Samsung in 1998

Evolution of Full Scope Simulator in Korea



Evolution of Full Scope Simulator in Korea (Stage I – Buying a ready made simulator)

1970's
1st Stage
Turn-Key
KRN #1(W) (1979)
Foreign Contractor (EAI:USA)
Technology Dependency



Vendor( Westinghouse) has supplied the Kori-1 NPP and a full scope simulator which is a copy of the Surry simulator

Kori#1(W PWR 3 loops) vs. Surry (W PWR 4 loops)

Evolution of Full Scope Simulator in Korea (Stage II- Replica FSSs / local sub contractor)

1980's
2nd Stage
Non Turn-Key
KRN #3(W)(1986), UCN #1(F)(1989)
Foreign Prime Contractors Local Sub-contractors
Technology Acquisition



Vendor( Westinghouse) has supplied a full scope simulator for KRN#2 with the co-work of local engineering company, KOPEC.

Vendor(Framatom) has supplied a full scope simulator for UCN#1 with the co-work of local engineering company, KOPEC.

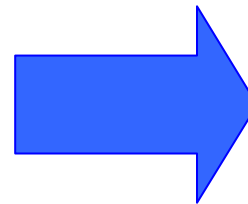
Evolution of Full Scope Simulator in Korea (Stage III - Replica FSSs / localization project)

PWR

1990's
3rd Stage
Technology Transfer
KRN#2(W)(1998), YGN #1(OPR)(1996), WSN#2(PHWR)(1998)
Local Prime Contractors Foreign Simulation SW
Technology Self-Reliance



PHWR



Evolution of Full Scope Simulator in Korea (Stage III – 3 Pack Project)

Technology Transfer

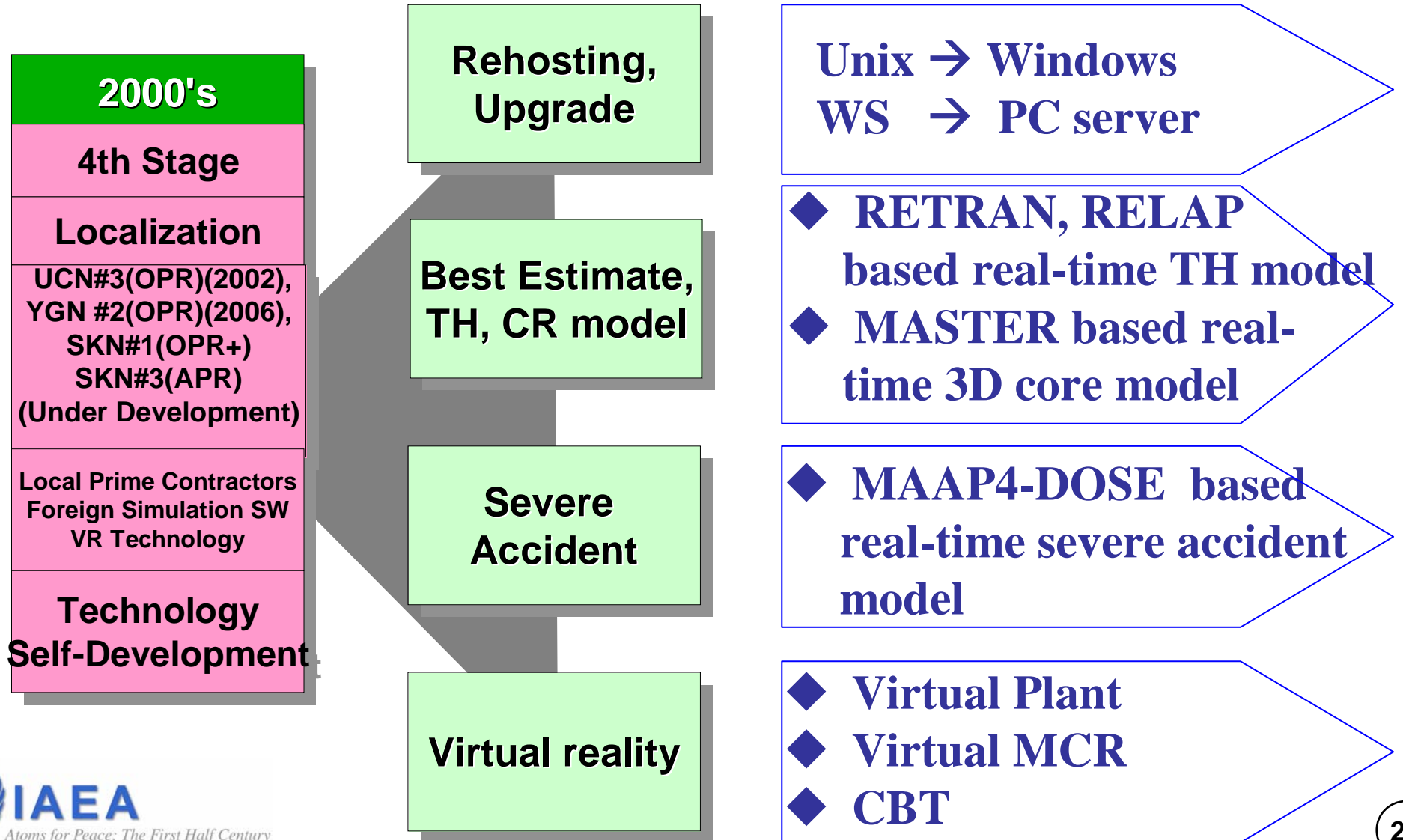


1994 Jump starting strategy

UNIX based Two(2) NPP FSSs + One(1) FP FSS



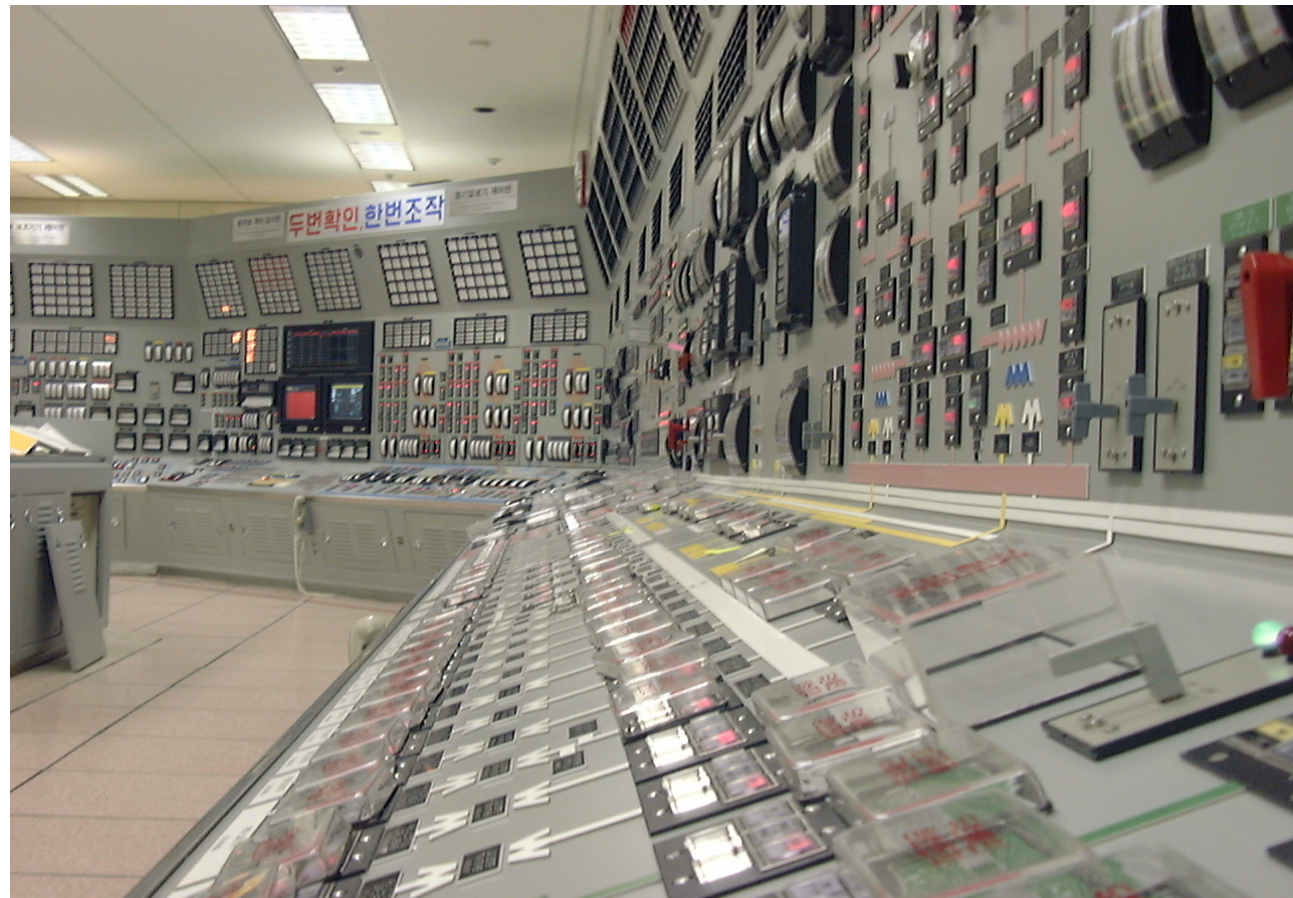
Evolution of Full Scope Simulator in Korea (Stage IV – Self Development)



Evolution of Full Scope Simulator in Korea (Stage IV – Rehosting & Upgrade)

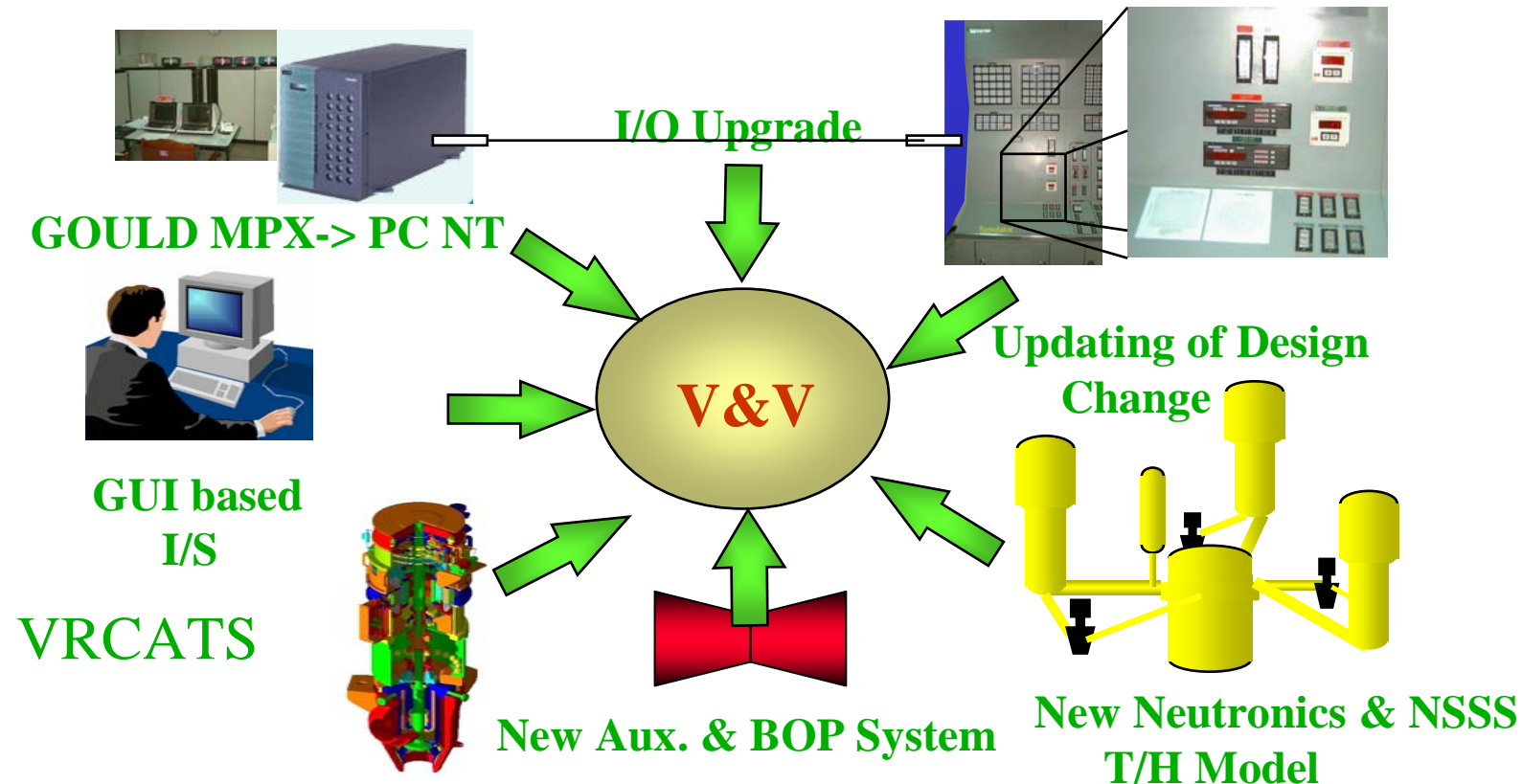
KNPEC-2 Simulator Upgrade

In January 2001,
KEPRI rehosted and
upgraded
the KNPEC-2(KRN#2)
Simulator.



Evolution of Full Scope Simulator in Korea (Stage IV – Rehosting & Upgrade)

Scope of KNPEC-2 Simulator Upgrade



Evolution of Full Scope Simulator in Korea (Stage IV – Re-hosting & Upgrade)

Technology	KNPEC-2 Simulator
Operating System & Executive	Windows- NT, SSP3.4™
Core Model	2 Group REMARK™
NSSS Thermal-hydraulics	RETRAN-3D based ARTS-01 (Advanced Real time Thermal-hydraulic Simulation model)
Fluid System Models	Single and Two phase model builder Flownet™, Gflow™ ,TOPMERET™
Instructor Station	Dataviews™
Classroom Training System	VRCATS -I (Virtual Reality Computer Assisted Training System)
Personal Training System	PCATS -I (Personal CATS) DBA included

Evolution of Full Scope Simulator in Korea (Stage IV – Developing Advanced FSS)

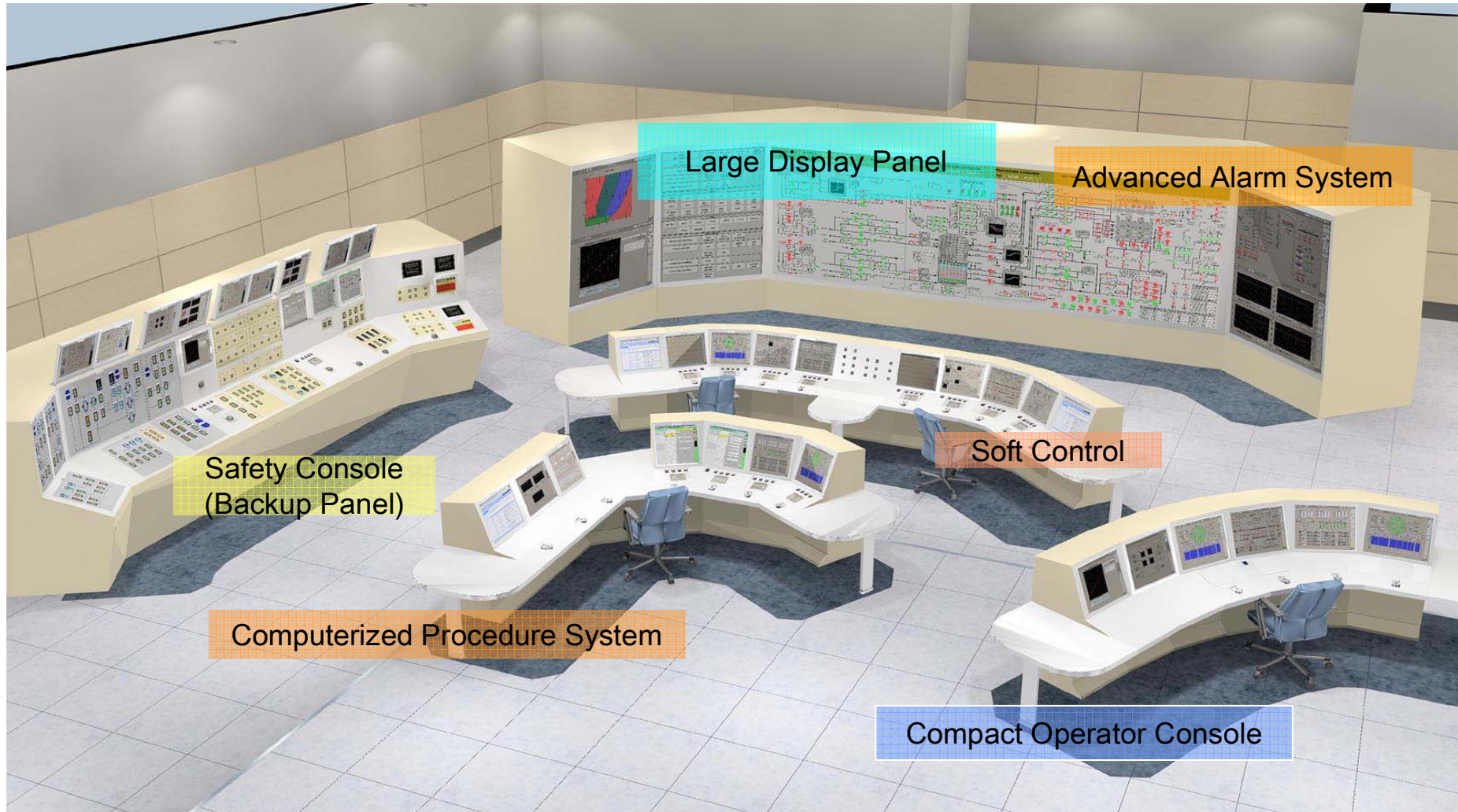
OPR1000(Korea Standard Nuclear Power)



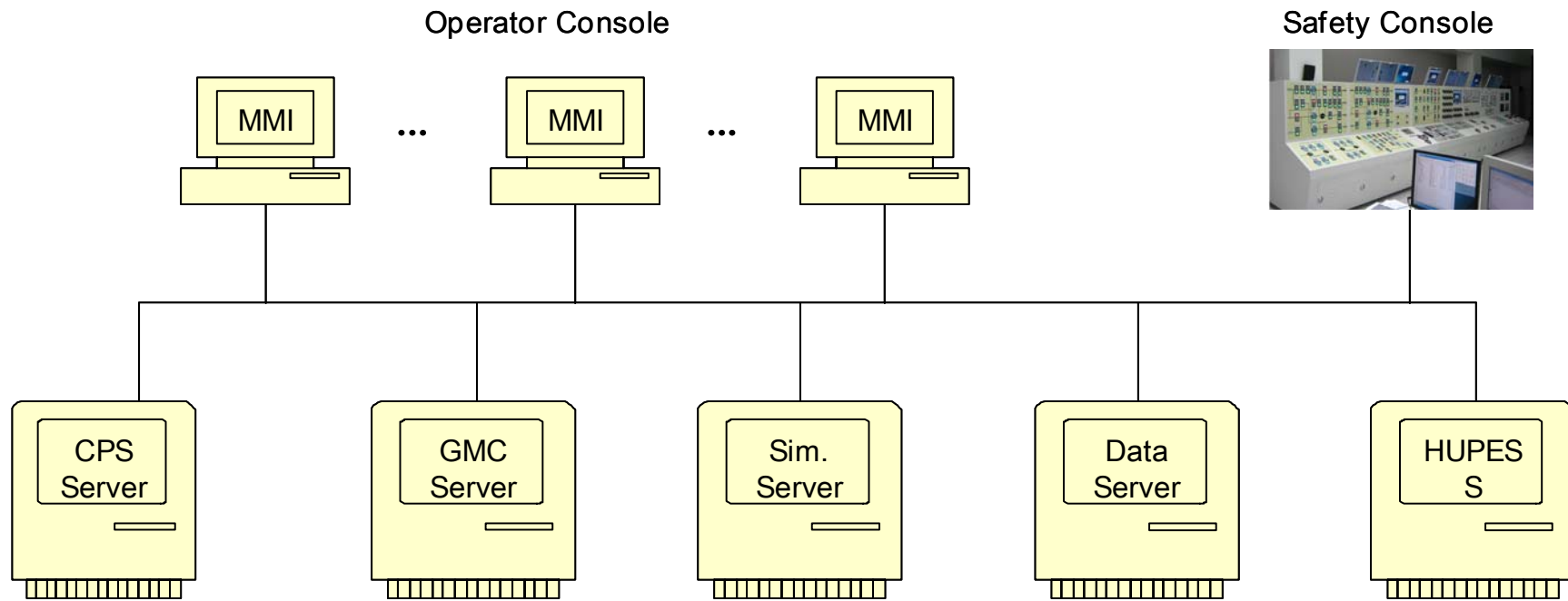
Evolution of Full Scope Simulator in Korea (Feature of OPR1000 FSS)

Technology	KSNP Simulator
Operating System & Executive	Windows-NT, SSP3.4
Core Model	REMARK™
NSSS Thermal-hydraulics	ARTS (←RETRAN3D)
Severe Accident Model	RSAM (←MAAP4-DOSE)
Fluid System Models	Single and Two phase model builder GFlow™, TOPMERET™
Logic and Central Models	CLASC™, Logic builder
Instructor Station	Dataviews™
Classroom Training System	VRCATS-II
Personal Training System	PCATS -II

Evolution of Full Scope Simulator in Korea (Main Features of APR1400 MCR)



Evolution of Full Scope Simulator in Korea (Feature of APR1400 FSS)



- CPS: Computerized Procedure System
- HUPES S: Human Performance Evaluation Support System
- GMC: General MMIs Control

Evolution of Full Scope Simulator in Korea (Stage IV – Best estimate engineering)

- **Fidelity Improvement by employing BE code as NSSS T/H engine for training simulator**
 - avoid negative training possibility due to overly simplified models and assumptions and can be used as safety evaluation tool for the transient analysis
- **Essential technology for developing the state-of-art training simulators**
 - Based on BE codes : USA (RELAP-R/T, theater..), France (CATHARE2), etc.
- **Why RETRAN?**
 - RETRAN is one of the most widely used in many utilities in the world.
 - Most of utilities have RETRAN specialist and input deck data base.
 - Using the safety analysis input for developing simulator T/H model gives cost and time saving
- **Easy for maintenance and upgrade**
 - Easy to replace with an up-to-dated RETRAN if needed
 - Usually no need to develop / improve NSSS T/H engine for training simulator

Evolution of Full Scope Simulator in Korea

ARTS(Advanced Real Time Thermal-Hydraulic Simulation)

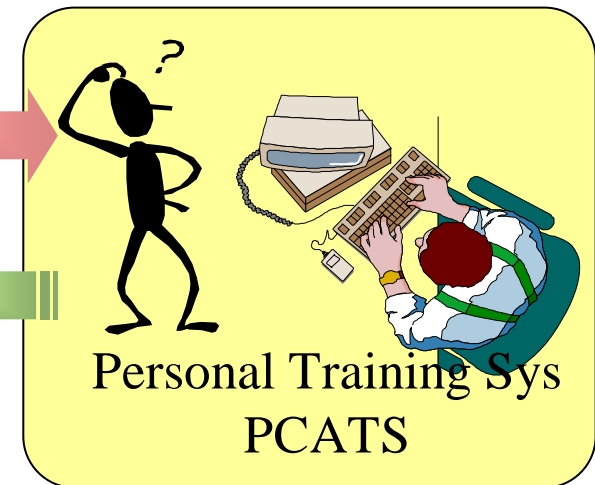
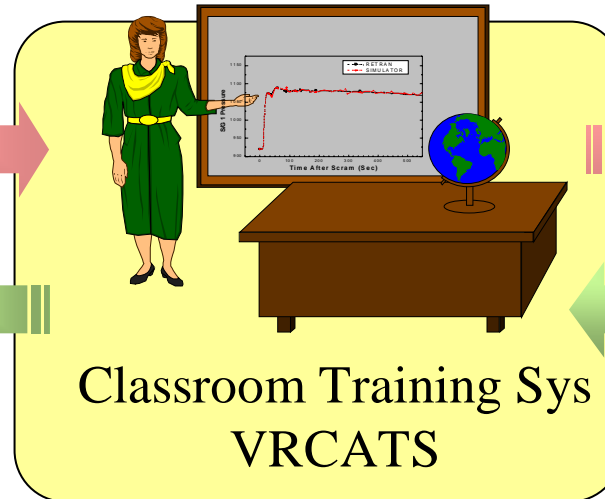
- **Development of backup calculation model for robustness**
 - **Limitation of RETRAN: difficult to simulate LBLOCA, mid-loop operation**
 - **Developed to insure the continuous calculation when ARTS fails**
- **RCS modeling: HEM (Homogenous Equilibrium Model)**
 - **Primary system two regions of pressurizer and RCS (mass, energy, momentum)**
 - **Secondary side of SGs single region for each SG (mass, energy)**
 - **ARTS Properties of all volumes and junctions are obtained explicitly using the calculation results of backup model**

Evolution of Full Scope Simulator in Korea

Improvement of RETRAN for ARTS

- **Improvement of robustness and real-time calculation capability**
 - **Simplifying state equation for liquid + noncondensable condition (drain operation)**
 - **Simplifying interfacial heat / mass transfer and heat transfer correlations and removing discontinuities**

Evolution of Full Scope Simulator in Korea (Full scope simulator - Classroom – Personal Training)



-For MCR Operators

- Operations, Skills, Rule
- S/W : Full Scope
- H/W Scope : MCR
- Requirements of Standard

- For MCR/Local Operators

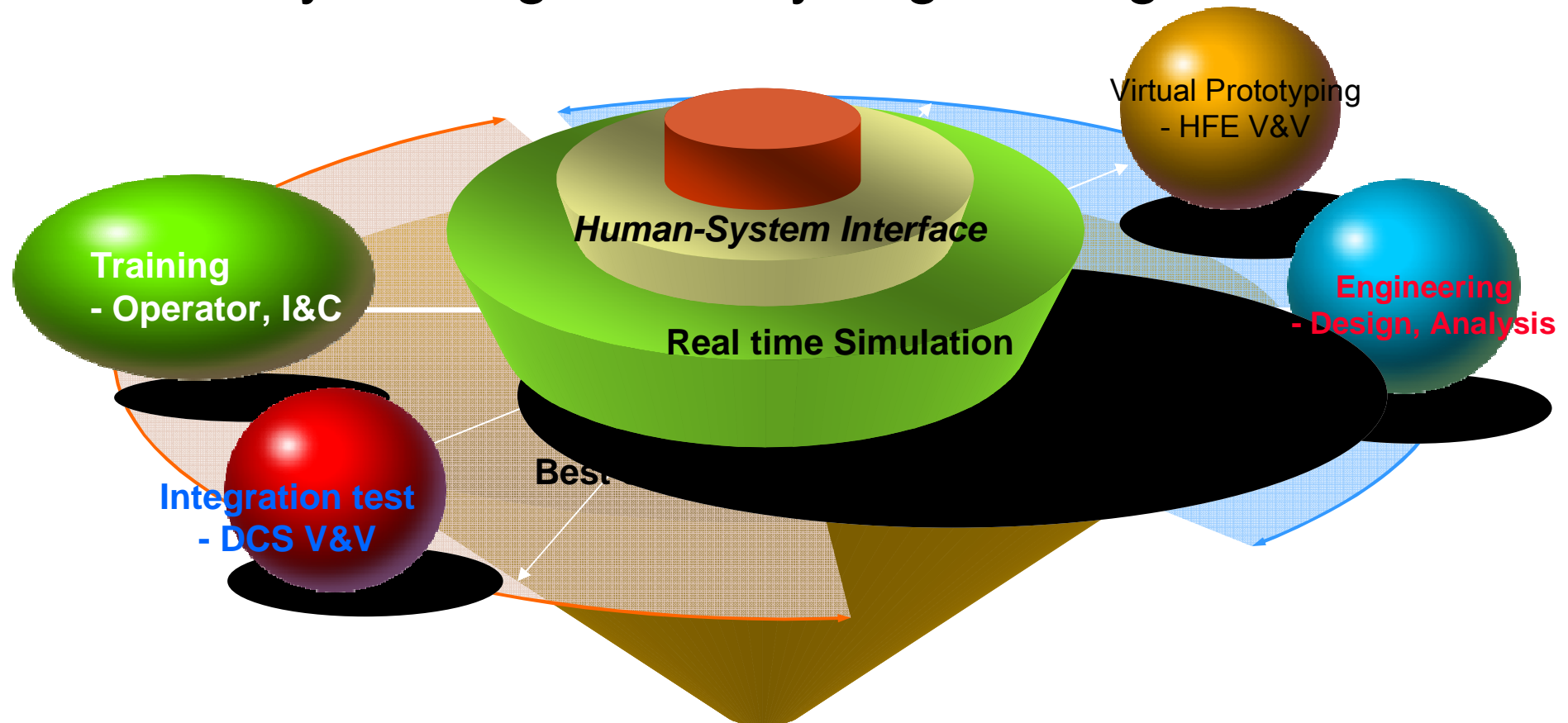
- Knowledge, Concepts Symptom
- S/W : Full Scope
- H/W Scope : MCR/Local Plant
- VR, Multimedia, MMI
- Instructor Assistance Tool

-For Operators/Personnel of the NPP

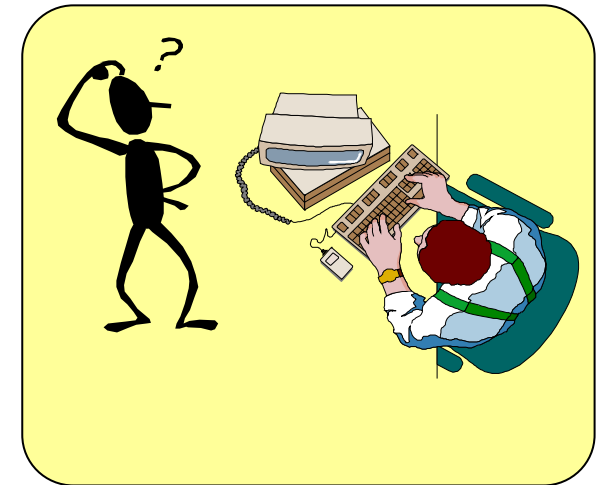
- S/W : Limited Scope
- GUI
- Self training System

Application fields of simulation technology

- ❑ Not only training but many engineering fields.



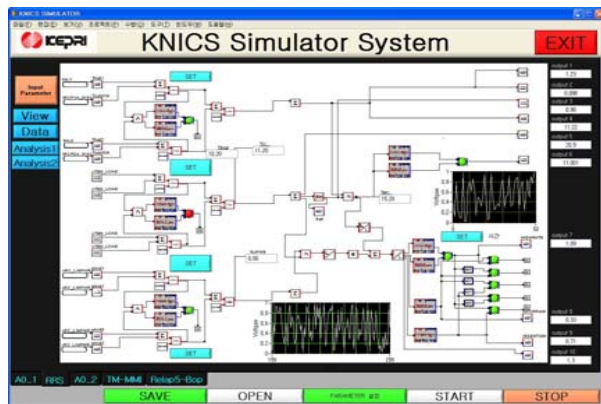
Application fields of simulation technology



Integration test

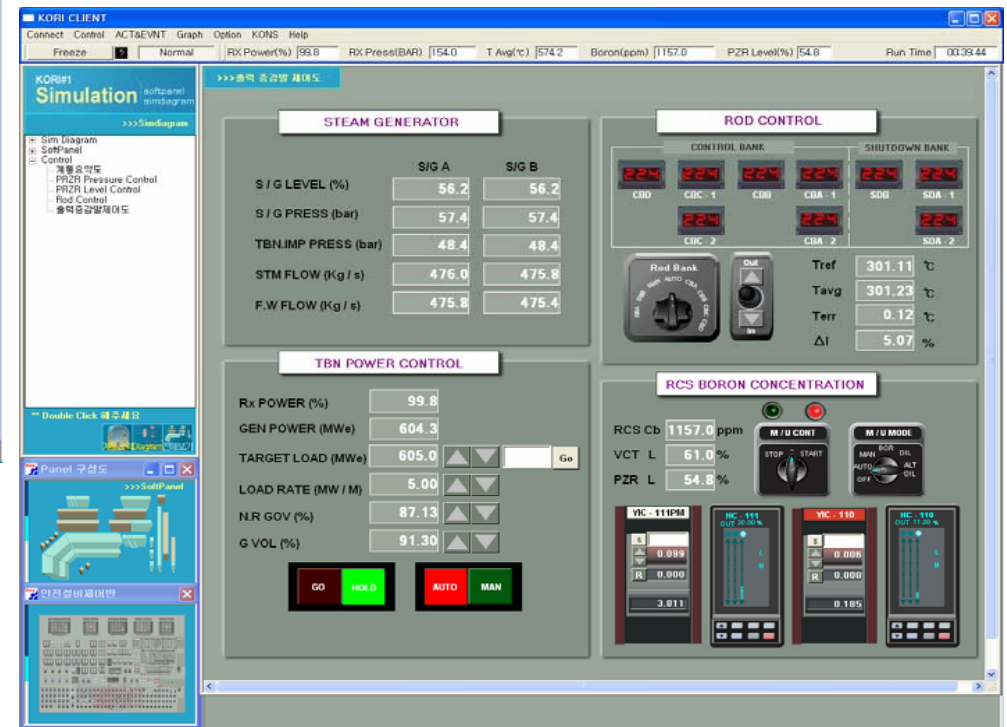
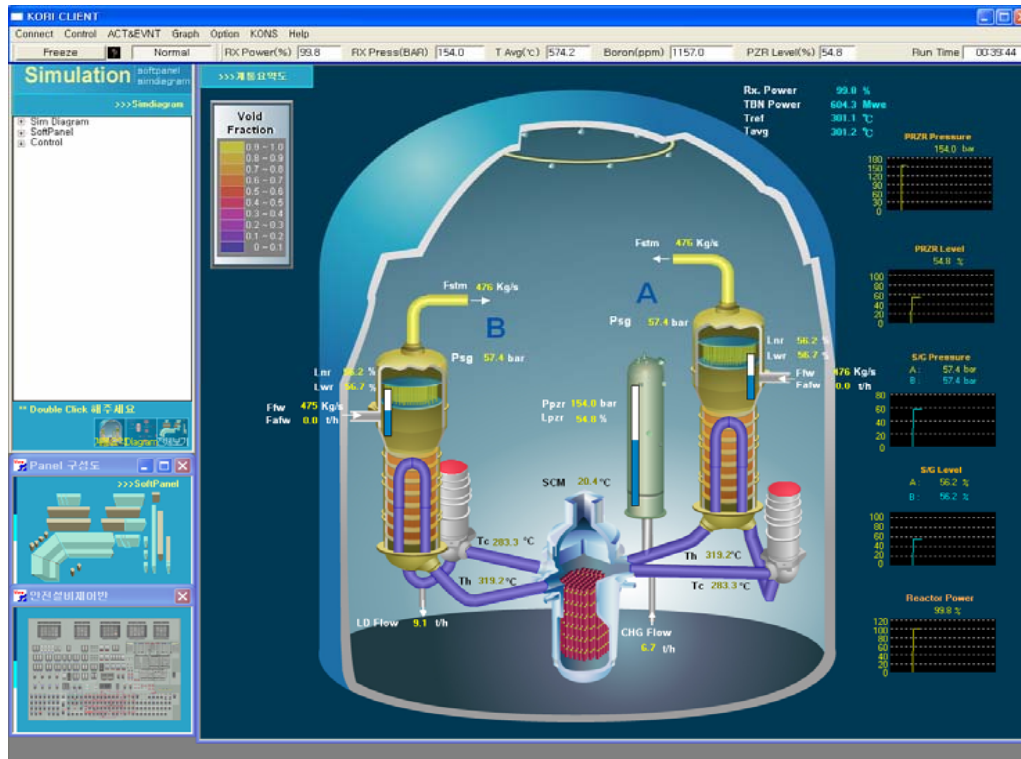
Engineering

Virtual Prototyping



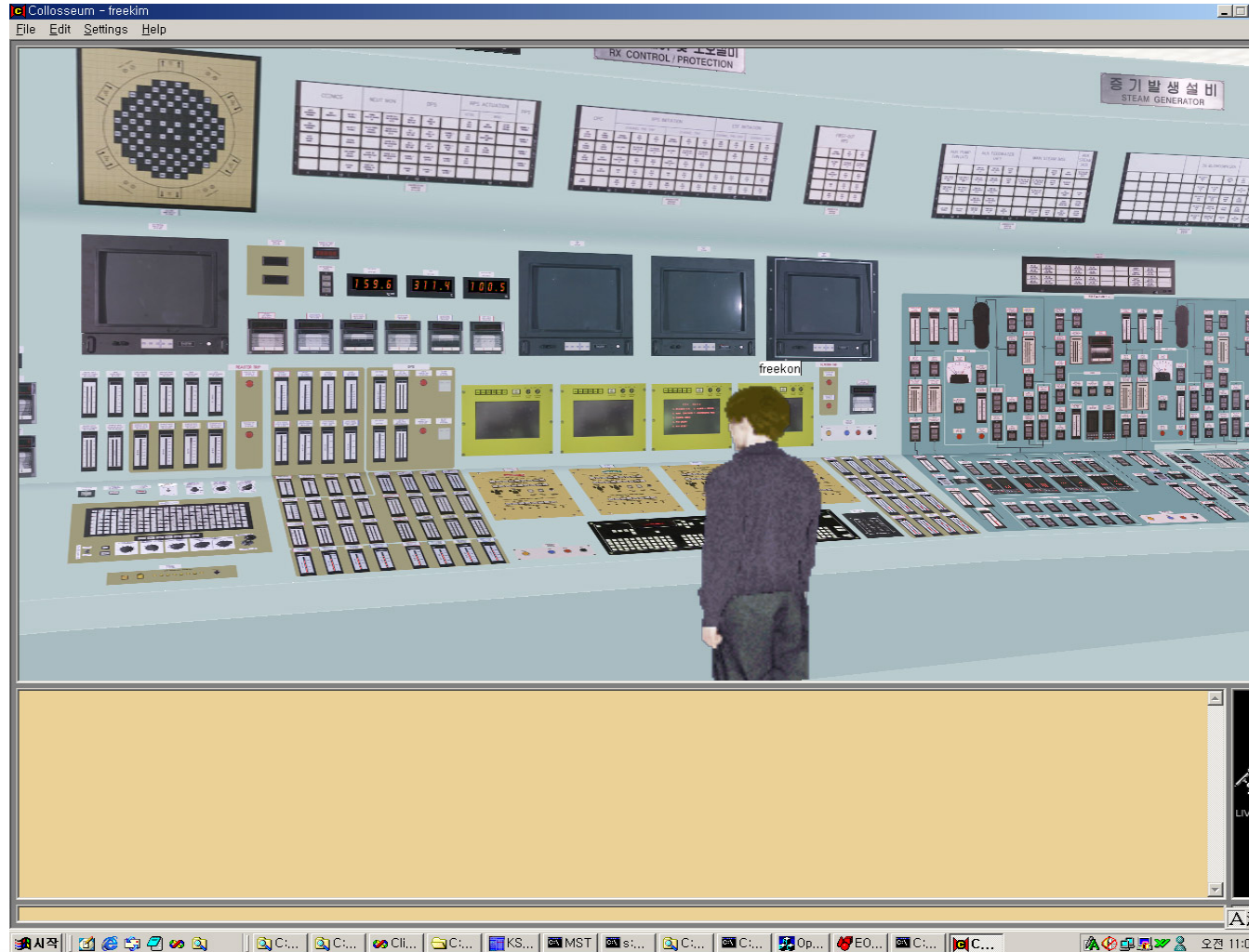
Application fields of simulation technology (cont'd)

MMIS-Nuclear plant analyzer



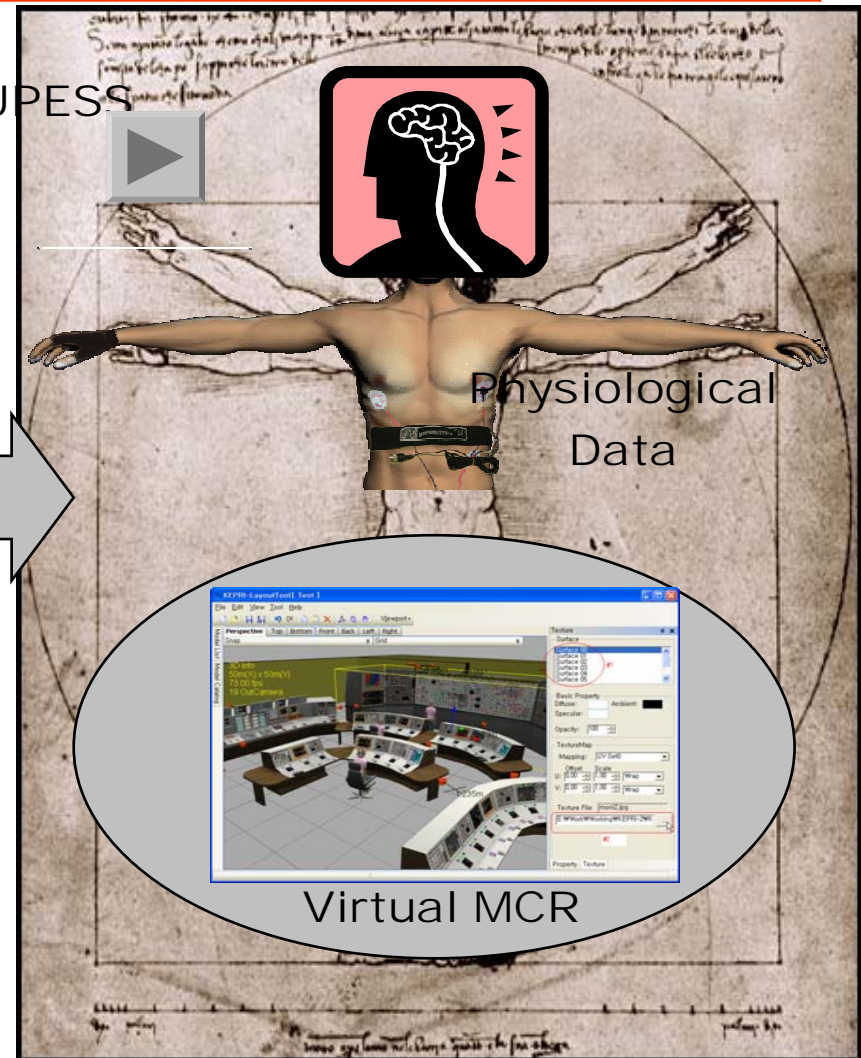
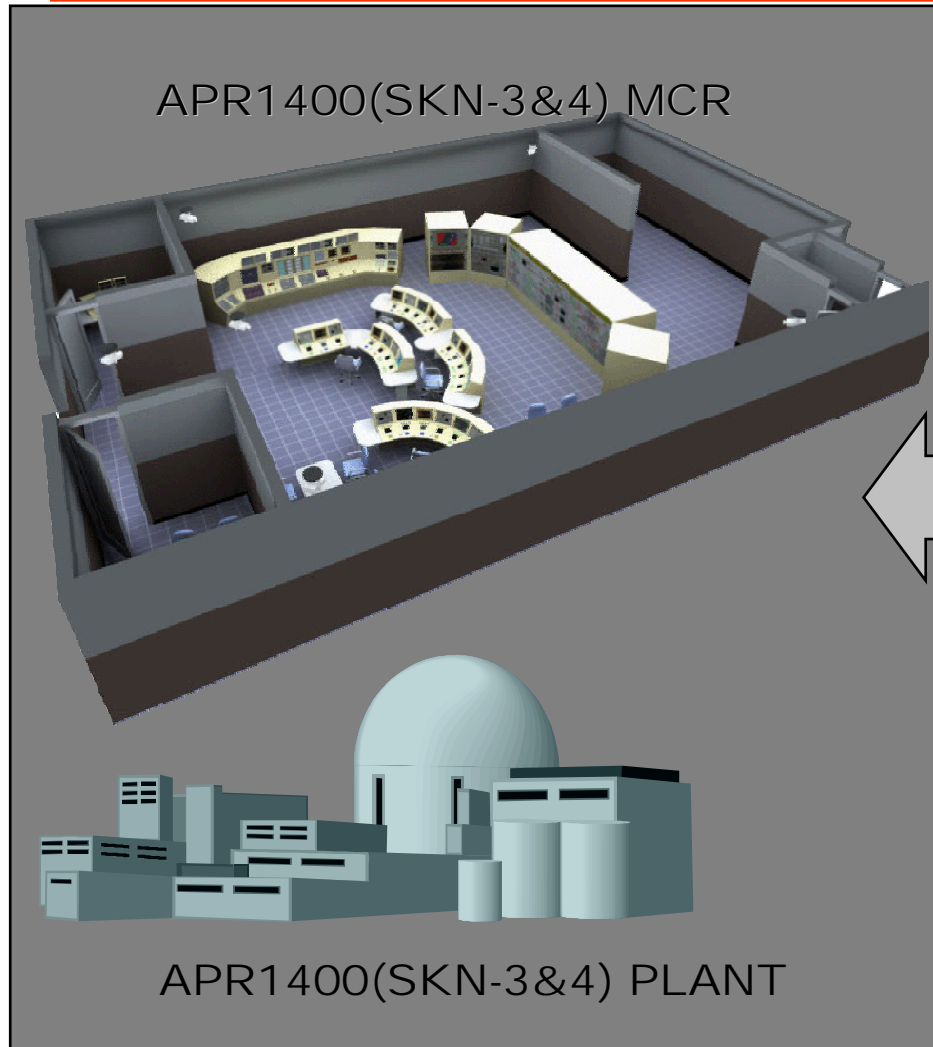
Application fields of simulation technology (cont'd)

CBT-VR MCR



Application fields of simulation technology (cont'd)

V&V of Human Factors Engineering (HFE)



Application fields of simulation technology (cont'd)

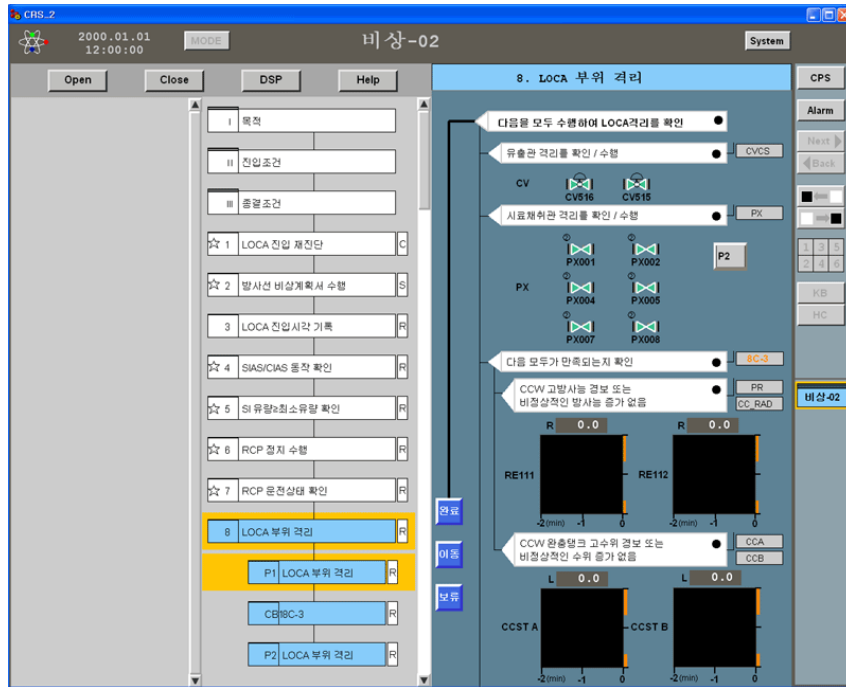
HFE Verification & Validation Activities for APR1400

Stage	Activities	Objective
Stage 1 (1998) Development	SV	<ul style="list-style-type: none"> ■ Demonstrating no existence of “show stopper” ■ HED (Human Engineering Deficiency) identification ■ Evaluate ACR MMI against conventional MMI
	PV	
Stage 2 (2000~2003) Development and Design Certification	PV1 (&SV1)	<ul style="list-style-type: none"> ■ Demonstrating basic adequacy for the various MMI resources ■ ACR (Advance Control Room) issue testing ■ HED identification ■ Evaluate ACR MMI against conventional MMI
	PV2 (&SV2)	
	PV3	
	PV4	
	PV5	
Stage 3 (2007~2010) Construction	PV6 (&SV3)	<ul style="list-style-type: none"> ■ Demonstrating that MCR ensemble supports safety operation and power production operation ■ Demonstrating basic adequacy for DCS/PLC MMI adopted ■ ACR issue testing ■ HED identification ■ Evaluate ACR MMI against conventional MMI
	PV7 (&SV4)	
	Final HFE V&V	



Application fields of simulation technology (cont'd)

Validation of Operating Procedure



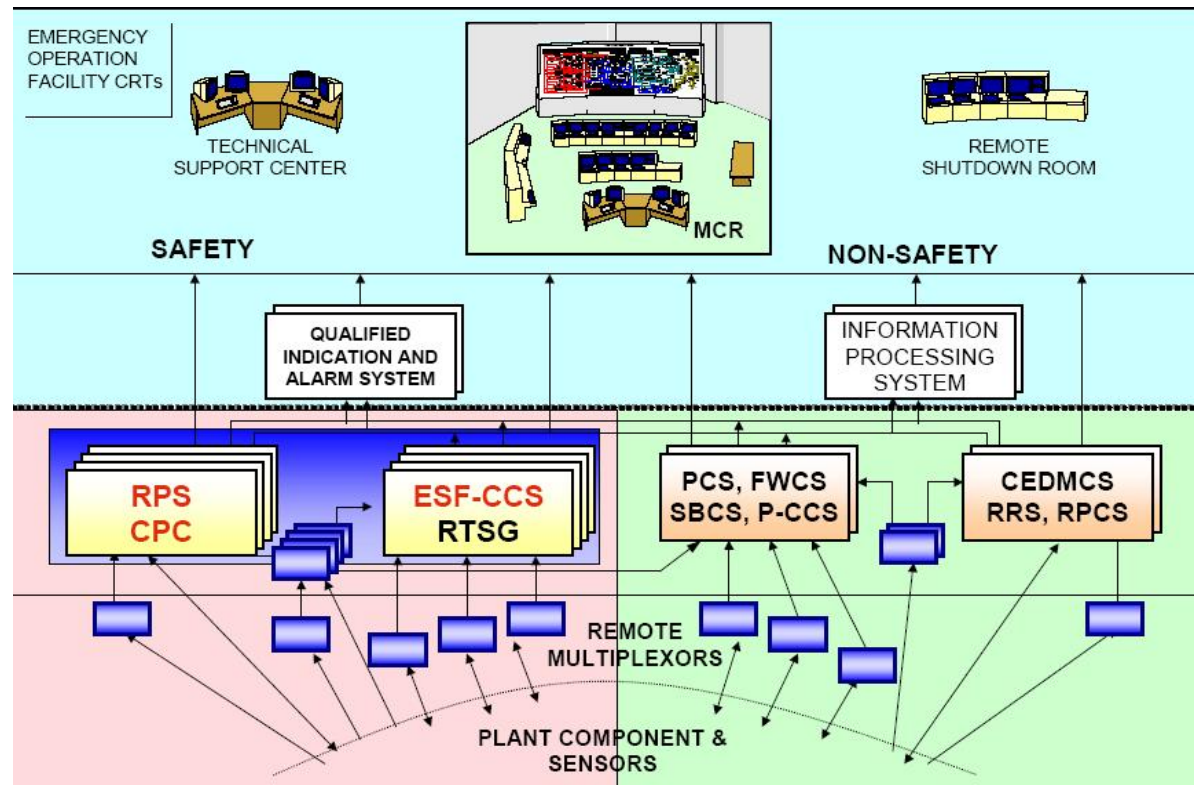
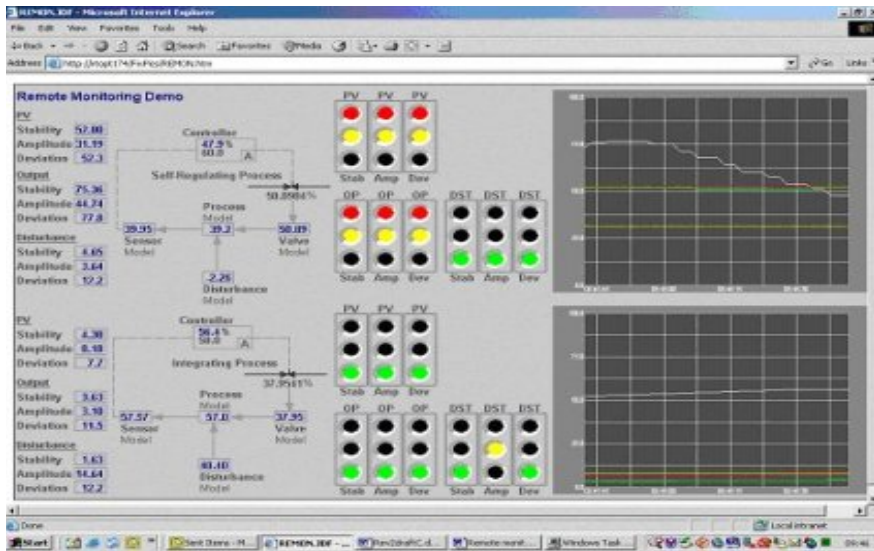
Computerized Procedure System for APR1400

Validating Operating Procedure by Using the Simulator



Application fields of simulation technology (cont'd)

DCS Integration test and V&V



Staff Training Program

■ Training Process



- KNPEI : KHNP Nuclear Power Education Institute
- Each Site (Kori, Wolsong, Ulchin, Yonggwang) has Training Center

Staff Training Program (cont'd)

■ Recruitment Program

No.	Course	Location	Duration
1	Orientation	KNPEI	3wks
2	Nuclear Theory Fundamentals	KNPEI	7wks
3	Nuclear Plant System Fundamentals	KNPEI	3wks
4	Plant Familiarization (OJT-I)	Site	7wks
5	System Details (Each Reactor Type)	Training Center	7wks
6	Plant Familiarization (OJT-II)	Site	6wks

* Totally 33 weeks required to cover all the fundamental courses.

Staff Training Program (cont'd)

■ Operator Training

No.	Course	Location	Duration
1	Operator Local Training	Site	6 weeks
2	FCO and OM Training	Site	4 weeks
3	MCR Operator Applicant	Training Center	10 weeks
4	Renewal training for RO/SRO License	Training Center	7 weeks
5	MCR Operator Refresher	Training Center	6 weeks

* The training center is one of the divisions in each NPP station.

Staff Training Program (cont'd)

■ MCR operators/unit

- 1 Shift supervisor/ 1 Safety supervisor
- 1 Reactor operator/ 1 Turbine operator
- 1 Electrical operator

■ Training Plan

- 6 weeks simulator training before initial fuel loading and then 2 weeks retraining every 4 month
- All MCR operators have to be trained using exactly same design simulator
- Seven simulators based on reactor design differences in KHNP

Organization of Staff Training (cont'd)

- **KNPEI : KHNP Nuclear Power Education Institute**
 - **Established as a Training Section in Kori NPP site**
 - **Authorized as the Training Center for Reactor Operators and RO/SRO Licensee Renewal Training Center by government**
 - **Awarded the “Letter of Recognition” as an excellent Training Center by IAEA**
 - **Taking charge of fundamental courses ; Nuclear theory, Plant system, C&I, Electrical maintenance, Safety culture, chemical control**

- **Training Center**
 - **Simulator training for operators including MCR and Local operator retraining course includes System and practical training for staffs each NPP division**
 - **Each NPP division (Kori, Wolsong, Ulchin, Yonggwang) has four training center**

Concluding Remarks

- **New Opportunities for Nuclear Power**
 - Energy and the environmental issues are at the core of future economic development
 - Climate Change Conventions and today's outstanding reliability of nuclear power can open new opportunities

- **New trend of energy policy seems to already begin**
 - Many countries think over nuclear power and phase-out policies
 - License renewal and power uprating are active worldwide
 - Worldwide efforts to develop new reactor systems are on the way

- **Simulation and VR technology are becoming new emerging technology for nuclear industries**

Concluding Remarks

- **Simulation and VR technology are becoming new emerging technology for nuclear industries . Application fields of NPP Simulation technology**
 - **Training ; Full Scope Training Simulator**
 - **Engineering ; Nuclear Plant Analyzer**
 - **HFE V&V, DCS V&V etc.**
- **Virtual Reality Applications on Nuclear Power industry**
 - **VRCATS, a web based classroom training system, is developed by KEPRI and it is one of example of the intelligent VR system which is connected with real time simulator.**
 - **VR is evolving from simple 3D interactive viewer to universal engineering interfacing solution and HSI V&V tools.**

