IAEA
60 Years
Atoms for Peace and Development

PC Based Basic Principle Simulators and IAEA Activities

Matthias KRAUSE, Tatjana JEVREMOVIC
Nuclear Power Technology Development Section

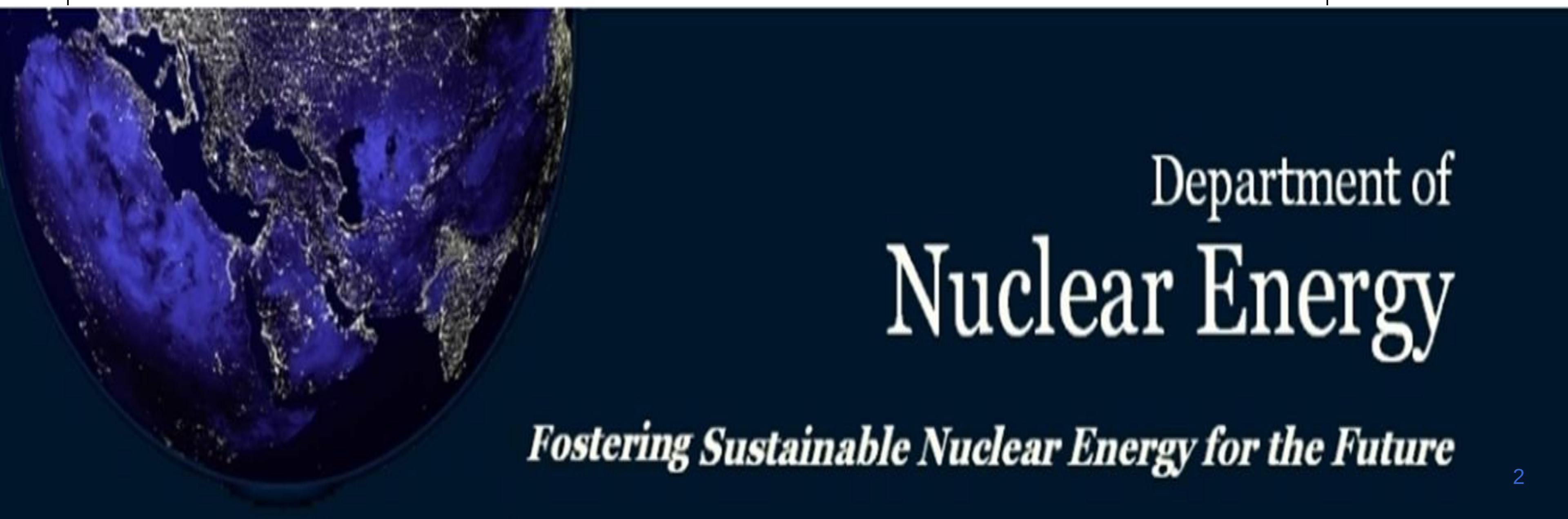
First Meeting of the Technical Working Group for Small Modular Reactors (TWG-SMR)

April 23 – 26, 2018

OUTLINE

Monday 19 February 2018 16:45 – 17:10

- IAEA PC Simulators in E&T in Member States
- iPWR Simulator



IAEA Programme Objective

"Assist Member States in training nuclear researchers, engineers, and nuclear regulators"

Systematic Education and Training on various topics

IAEA established an Education & Training Courses based on **active learning (learning-by-doing)** with nuclear reactor simulation computer programs (**basic principle simulators**) to assist Member States in educating & training their nuclear professionals.

- Basic Principle Simulators provide a thorough demonstration of the basic operational principles of NPPs by illustrating general concepts, and demonstrating and displaying fundamental physical processes of the plant:
  - Operational characteristics
  - Reactivity control systems
  - Safety systems
  - Responses to transients and accidents.

- Used in Reactor Technology Assessment Stage
  - The best technology for a national objective and needs
  - Training in reactor technologies
  - Learning of the technology specifics: **ARIS data base** →

Computer based tools are a state of the art learning approach

- EXAMPLES are PC simulators of nuclear power plants' operation and responses to various inputs (transients, accidents) with illustrative screens and graphs to provide the plant's response
- IAEA PC based simulators are designed to provide insight and understanding of the general design and operational characteristic of various power reactor systems:
  - PWR, BWR, WWER, PHWR, iPWR and have

Focus on education and training in classrooms, and not licensing or reactor operator training, or benchmarking against other computer codes and methods

TYPES of Simulators

❑ Basic Principle Simulators

- Operate on personal computers (PC) and are provided for a broad audience of technical and non-technical personnel as an introductory educational & training set of tools
- Configuration suited to classroom & self - learning tool as complement to textbooks and manuals
- Provides subsystem training and overall plant training (startup, shutdown, malfunctions)

❑ Engineering Simulators

- ❑ Computer based simulation tools able to calculate and display in real time the physical parameters of NPP
- ❑ Maintenance and retraining

❑ Full Scope Simulators

Indispensable in the licensed training of the NPP control room operators:

- Plant operation in a control room environment

- Procedure based, cognitive skill based, team work

TYPES of Simulators

- Basic Principle Simulators

ROLE

- Provide initial and fundamental educational training about NPP (including NPP personnel before NPP is built & full scope simulator in service)
- Provide knowledge of system interfaces, integration and interactions

SPECIFICS

- Relatively low cost and affordable
- Can use highly portable, standard PC platforms
- Mathematical models are easily configurable and provide flexibility of use
- Can use graphic icons, control pop-ups, time trends for user interfaces instead of hardwired panels

The use of the IAEA PC based basic principle simulators in education and training is aimed at **enhancing understanding of nuclear technologies through learning-by-doing:**

Hands-on experiential training is highly suitable for operators, maintenance technicians, suppliers, regulators and engineers

Train the Trainer

Base for Technology Assessment

List of the IAEA PC-Based Basic Principle Simulators

Pressurized Water Reactor (PWR) Simulators

- ❑ Gen II Pressurized Water Reactor (PWR)
- ❑ 2-Loop Large PWR (Korean-OPR 1000)
- ❑ Russian-type PWR (WWER-1000)
- ❑ Advanced Passive PWR (AP-600)
- ❑ Integrated Pressurized Water Reactor (SMR)

Issued in January 2017

Boiling Water Reactor (BWRs) Simulators

- ❑ Advanced Boiling Water Reactor (BWR)
- ❑ Advanced Passive BWR (ESBWR)

Pressurized Heavy Water Reactor (PHWR)

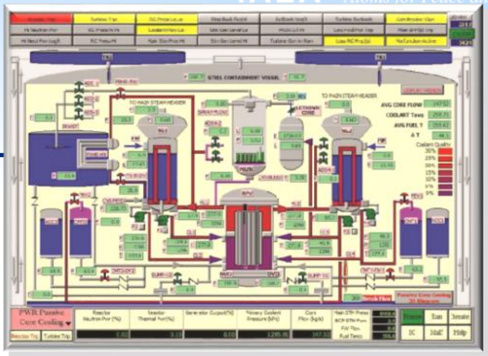
- ❑ Conventional PHWR
- ❑ Advanced PHWR (Candu-6)

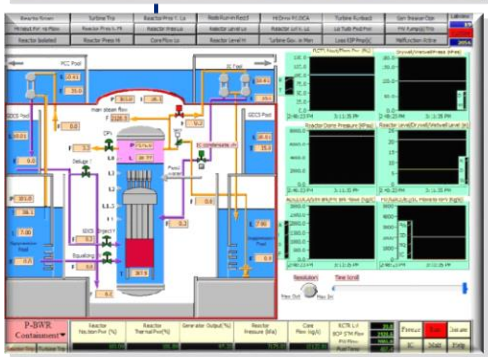
Part-Task Simulator

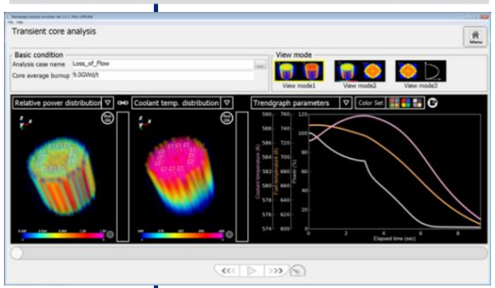
- ❑ Micro-Physics Simulator (Lite)

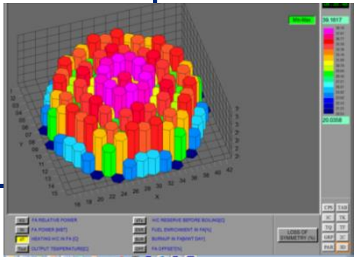
Under Development

- ❑ Sodium Cooled Fast Reactor (SFR)
- ❑ High Temperature Gas Cooled Reactor (HTGR)









IAEA 60 Years Atoms for Peace and Development

List of PC-Based Simulators

Simulator Name	*Type*	*Developer*	*Funded by*	
Standard 2-Loop PWR	A generic two-loop PWR with inverted U-bend steam generators and dry containment similar to existing Westinghouse, Framatome or KWU designs.	Micro-Simulation Technology of USA	IAEA	
2-Loop Large PWR	Represents Korea's 1000 MWe Optimized PWR	KAERI	Korea	
Advanced PWR	Largely based on Westinghouse AP-600 PWR with passive safety systems	Cassiopeia Technologies Inc. (CTI) of Canada	IAEA	
WWER-1000	WWER-1000 reactor is a vessel-type Light Water Reactor where chemically purified water with boric acid serves as coolant and moderator.	Moscow Engineering and Physics Institute in Russia	Russia	
Standard BWR	A typical 1300 MWe BWR with internal recirculation pumps similar to ABWR plant	Cassiopeia Technologies Inc. (CTI) of Canada	IAEA	
Advanced BWR	Represents GE's ESBWR with passive safety features	Cassiopeia Technologies Inc. (CTI) of Canada	IAEA	
Conventional Pressurized Heavy Water Reactor (PHWR)	Represents a 700 MWe class CANDU-6 reactor	Cassiopeia Technologies Inc. (CTI) of Canada	IAEA	
Advanced PHWR	Represents the ACR-700 system	Cassiopeia Technologies Inc. (CTI) of Canada	IAEA	
Micro-Physics Simulator (Lite)	Core Physics Simulator (Part Task)	Nuclear Engineering Ltd. (NEL)-Japan	NEL Japan	
iPWR	***Small Modular Reactor (SMR)***	***TECNATOM- Spain***	***IAEA***	***Available 2017***
PWRsim	***Pressurized water reactor***	***KSU – Sweden***	***KSU***	***Available 2017***
BWRsim	***Boiling Water Reactor***	***KSU – Sweden***	***KSU***	***Available 2017***

NEW

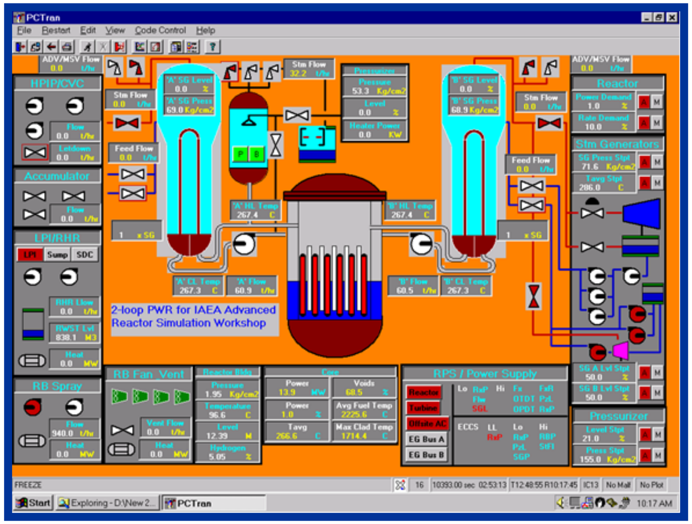
Preparation of the training materials

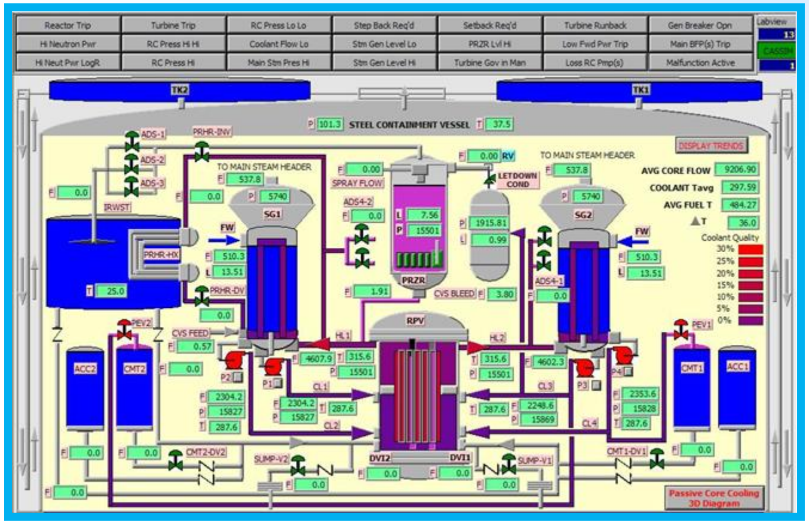
CFE, Interns

Basic Principle Simulators: Audience?

IAEA 60 Years *Atoms for Peace and Development*

Effective hands-on educational & training tools





The use of the IAEA PC based basic principle simulators in education and training is aimed at **enhancing understanding of nuclear technologies through learning-by-doing:**

Train the Trainer

Support Reactor Technology Assessment

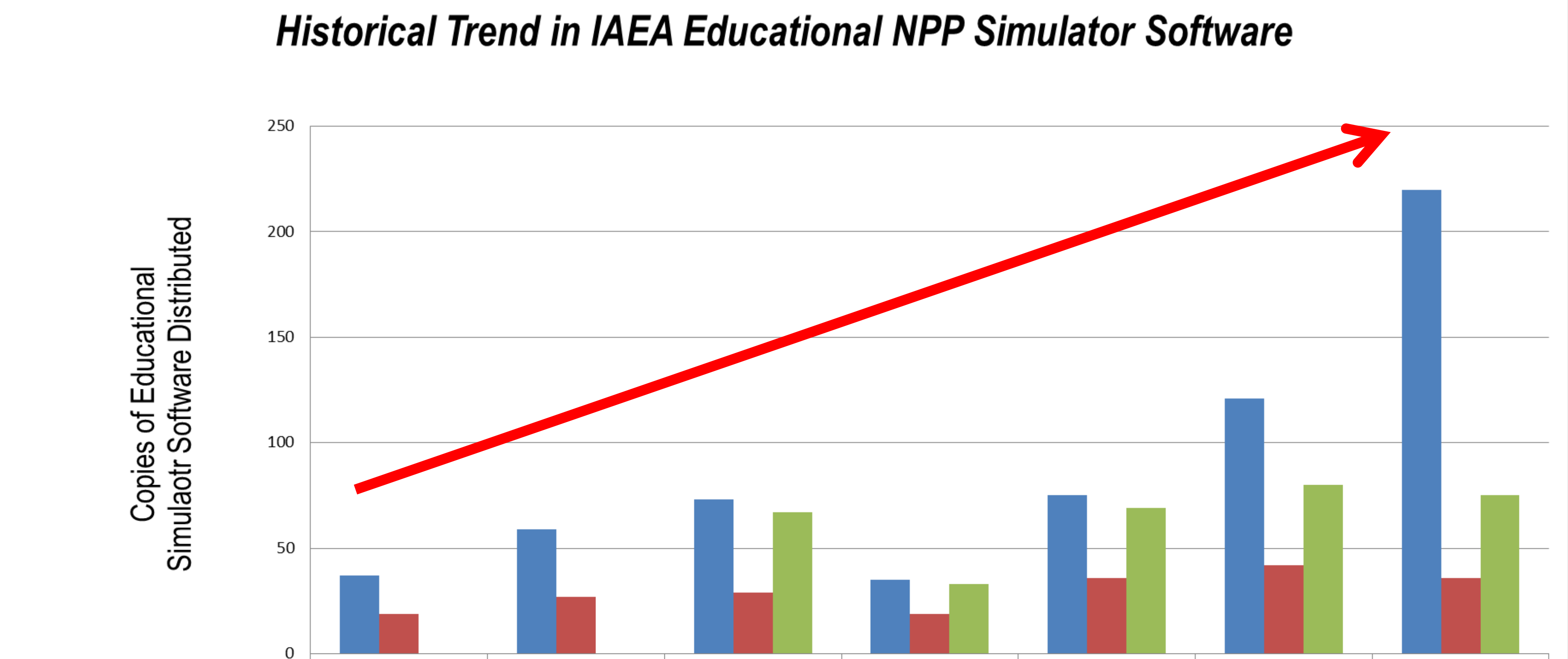
→ Hands-on experiential training is highly suitable for operators, maintenance technicians, suppliers, regulators and engineers.

TM ON DEVELOPING A SYSTEMATIC EDUCATION AND TRAINING APPROACH USING PERSONAL COMPUTER BASED SIMULATORS FOR NUCLEAR POWER PROGRAMMES HELD IN VIENNA, AUSTRIA, 15 – 19 MAY, 2017

1) **TECDOC January 2018**
2) **TM – Continuation: 23-27 April 2018 Wuhan, China**

32 experts from 21 Member States

Software Distribution



	2008	2009	2012	2013	2014	2015	2016
Copies of Software Distributed	37	59	73	35	75	121	220
Number of Member State Requests	19	27	29	19	36	42	36
Number of Different Organizations			67	33	69	80	75

	2017	1Q 2018
Copies Distributed	562	65
No. of MS Requests	25	9
No. of Organizations	63	9

Human Capacity Building: Active Learning with Education and Training Courses Using PC Based Basic Simulators

Understanding Physics and Technology of WCRs/FRs/HTGRs

IAEA 60 Years
Atoms for Peace and Development

No.	Year	Dates	Title	Location	Funding Organization	
1	1999	November 22-26	Workshop on Reactor Simulator Development	Vienna, Austria	NPTDS	
2	2000	16-27 October	Workshop on the Application and Development of Advanced Nuclear Reactor Simulators for Educational Purposes	Trieste, Italy	NPTDS	
3	2001	29 October to 9 November	Workshop on Advanced Nuclear Simulation	Trieste, Italy	ICTP-NPTDS	
4	2002	14 - 25 October	Workshop on Advanced Nuclear Power Plant Simulation	Trieste, Italy	ICTP-NPTDS	
5	2003	27 October – 7 November	Workshop on Nuclear Power Plant Simulators for Education	Trieste, Italy	ICTP-NPTDS	
6	2004	8 to 19 November	Workshop on Nuclear Power Plant Simulators for Education	Trieste, Italy	ICTP-NPTDS	
7	2005	31 October – 11 November	Workshop on Nuclear Power Plant Simulators for Education	Trieste, Italy	ICTP-NPTDS	
8	2006	3-7 July	Workshop on NPP Simulators for Education	Bucharest, Romania	TC Project ROM9026	
9	2007	29 October - 9 November	Workshop on Nuclear Power Plant Simulators for Education	Trieste, Italy	ICTP-NPTDS	
10	2009	12 - 23 October	Workshop on NPP Simulators for Education	Trieste, Italy	ICTP-NPTDS	
11	2011	3 - 14 October	Workshop on Enhancing Nuclear Engineering through the Use of the IAEA PC-based Nuclear Power Plant Simulators	Milano, Italy	NPTDS	
12	2012	*3-4 October*	Present paper at European Nuclear Power Plant Simulation Forum 2012	Barcelona, Spain	NPDTS	
13	2013	4 - 15 November	Course on Physics and Technology of Water Cooled Reactors through the Use of PC-Based Simulators	Madrid, Spain	In cooperation	
14	2013	03-07 June	Interregional Course on Fundamentals of Pressurized Water Reactors with PC-Based Simulators	Daejeon, Korea	TC Inter-regional	27
15	2014	15-19 December	Understanding the Physics and Technology of Advanced Passively Safe Water-Cooled Nuclear Reactors using Basic Principles Simulators	Bangi, MALAYSIA	TC Funded	24
16	2015	16-28 February	Physics and Technology of Water-Cooled Reactors through the use of PC-based Simulators	Trieste, Italy	ICTP-NPTDS	35/118
17	2015	4-8 May	Understanding the Physics and Technology of Advanced Passively Safe Water-Cooled Nuclear Reactors using Basic Principles Simulators	Santiago, CHILE	TC Funded	15
18	2015	1-5 June	Course on Fundamentals of Pressurized Water Reactors with PC-based Simulators	Daejeon, Korea	In cooperation with KAERI	20
19	2015	22-27 November	Course on Fundamentals of Pressurized Water Reactors with PC-based Simulators	Amman, Jordan	TC Funded	16
20	2015	7-18 December	Physics and Technology of Water-Cooled Reactors through the use of PC-based Simulators	TAMU, Texas	TC Funded	28
21	2016	May 23- June 3	Physics and Technology of PWRs with PC-based Simulators	Daejeon, Korea	In cooperation with KAERI	18
22	2016	11-15 July	Understanding the Physics and Technology of PWRs through the use of PC-based Simulators	Tunis, Tunisia	In cooperation with AAEA	14
23	2016	24-28 October	Understanding the Physics and Technology of PWRs through the use of PC-based Simulators	Ocoyoacac, Mexico	TC Funded	

23 Simulator Training Courses held across the world

2000 - 2016

2018

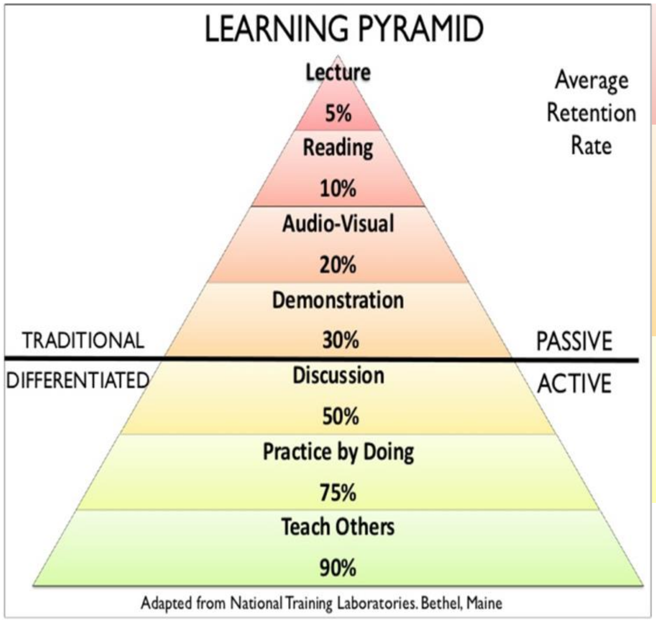
30 National Advanced WCRs: Physics, Technology, Passive Safety, and Basic Principle Simulators, 22-26 Jan, Pakistan

31 Regional Training Course on Pressurized Water Reactor Technology Using PC Based Basic Principle and GlassTop Nuclear Power Plant Simulators, 19-23 Feb, UAE

2017

24	Pilot Training on WCR Technologies and Severe Accidents with Simulators	Salt Lake City, USA February 2017	Okayama University, Japan	13
25	IAEA/KAERI Regional Course on WCRs Technologies and Passive Systems: Competence Based-Approach with PC-Based Basic Principle Simulators	KAERI, RoK September 2017	TC, KAERI	20
26	WCR Technology with the Use of PC Based Basic Principle Simulators	Singapore	Singapore	15
27	Training Course on Reactor Technologies and Severe Accidents: Learning-by-Doing with PC Simulators	Salt Lake City, USA November 2017	Okayama University, JAIF, Japan	15
28	Understanding Technology and Physics of WCRs with PC Simulators	ICTP, Italy November 2017	ICTP, TC, NPTDS	20
29	IAEA/VINATOM National Training Course on PWRs Technologies and Passive Safety Systems	Hanoi, Vietnam December 2017	TC, VINATIOM	20

Rationale for the Training Courses and Workshops



- Use of PC Simulation in three steps:
  - **Lectures**: Overview reinforcing the theoretical concepts
  - **Demonstration**: Explanation on simulators and demonstration of representative examples (accidents, transients,…)
  - **Practice by doing**: actual hands on use of simulators performing normal and accident based scenarios
- Evaluation: feedback and discussion regarding outcome and performance at team and individual levels

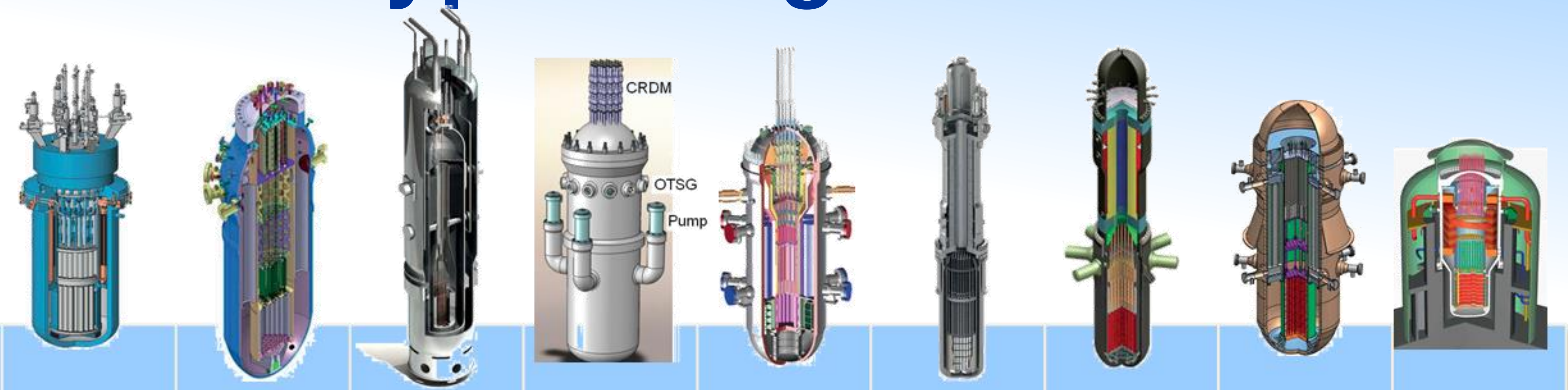
Feedback from PC – Based Learning with Simulators

60 Years
IAEA
Atoms for Peace and Development

- Enhanced understanding of theoretical concepts and longer term retention
- **Ability to relate theory with operational factors**
- Appreciation for safety and security
- Better understanding of the intricate relationship between reactor physics concepts and thermal hydraulic principles
- **Appreciation for system based approach to problem solving**
- Appreciation for clear and effective communication
- Greater comprehension and appreciation for related concepts (health physics, fuel cycle, etc.)
- Ultimately, better prepared to hit the ground running upon graduation and employment in the industry.

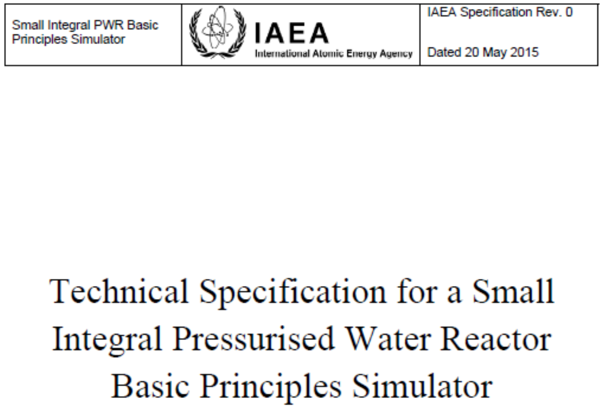
Mahmoud Ghavi, Ph.D.
Professor and Director of the
Southern Polytechnic State University Center for Nuclear Studies

SMR – iPWR type: integration of NSSS



Integration of components	ABV-6M	CAREM	NuScale	ACP100	SMART	mPower	W-SMR	IRIS	IMR
Pressurizer	√	No prz	√	outside	√	√	√	√	√
Steam Generators	√	√	√	√	√	√	steam drum outside	√	√
Pumps	NC	NC	NC	√	√	√	√	√	NC
CRDMs	√	√	ext	ext	ext	√	√	√	ext
Power MWth MWe	38 **6**	100 **25**	160 **45**	310 **100**	330 **100**	530 **180**	800 **225**	1000 **335**	1000 **350**

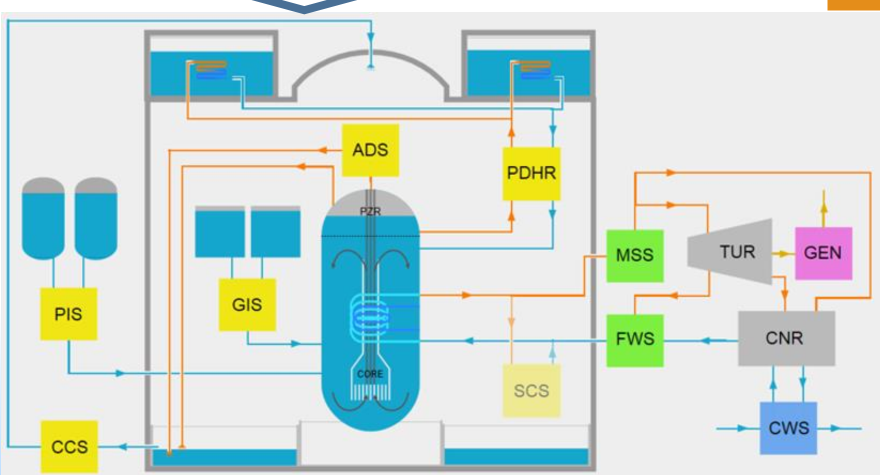
iPWR Development 2015-2017

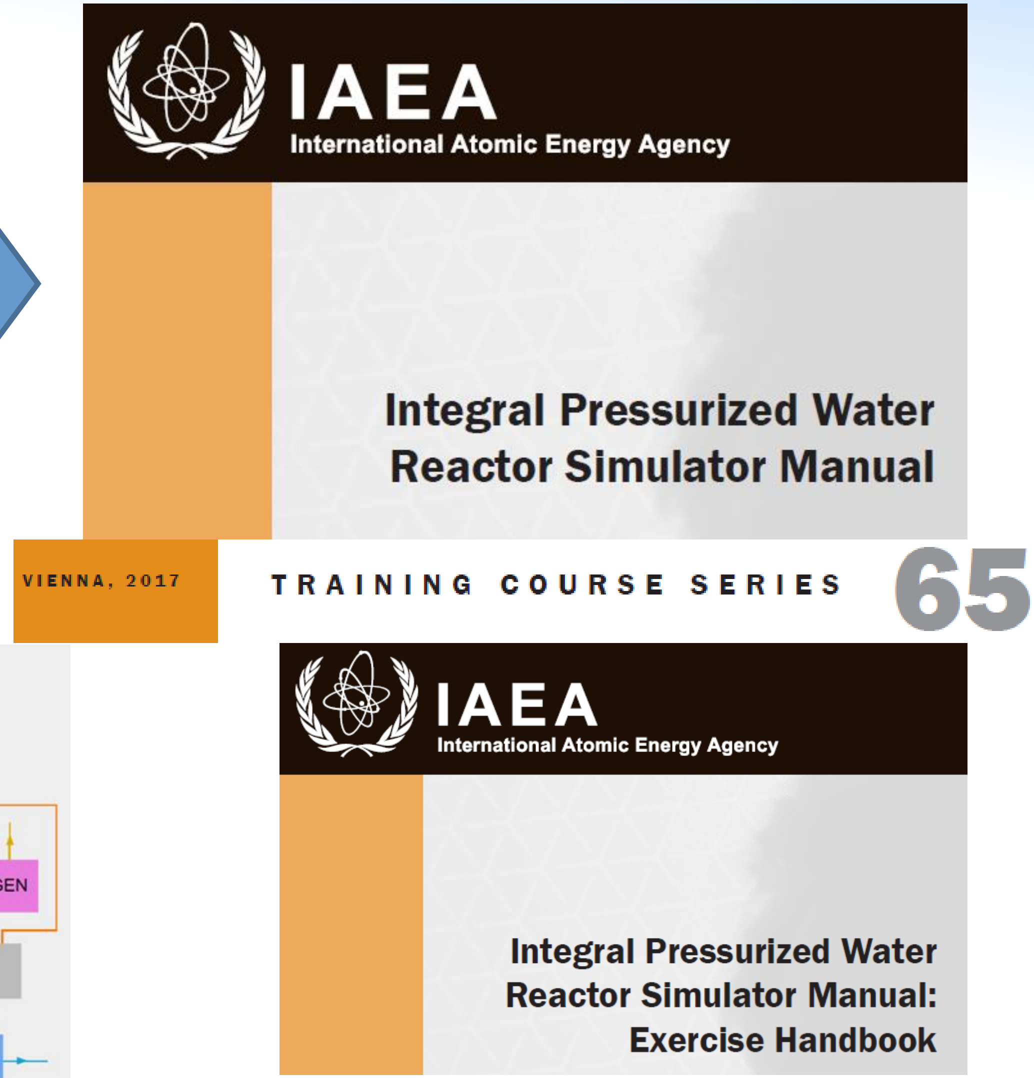


Small Integral PWR Basic Principles Simulator	IAEA International Atomic Energy Agency	IAEA Specification Rev. 0 Dated 20 May 2015

Technical Specification for a Small Integral Pressurised Water Reactor Basic Principles Simulator

Nuclear Power Technology Development Section (NPTDS)





IAEA
International Atomic Energy Agency

Integral Pressurized Water Reactor Simulator Manual

VIENNA, 2017

TRAINING COURSE SERIES 65

IAEA
International Atomic Energy Agency

Integral Pressurized Water Reactor Simulator Manual: Exercise Handbook

Integral Pressurized Water Reactor Simulator (SMR)

The iPWR simulator operational specifics are:

- Designed to examine the primary and balance of plant (BOP) behaviour of the iPWR
- Operation under accident conditions: Safety systems are implemented including Gravity Driven Water Injection System, Pressure Injection System, Passive Decay Heat Removal system, and Protection and Control System
- Severe accidents include a station blackout (SBO): the users can initiate the SBO accident by loading SBO malfunction. It will automatically trip both the reactor and the reactor turbine, and subsequently, actuate Passive Decay Heat Removal System (PDHR). The reactor behaviour can be observed during SBO until the reactor becomes stable.

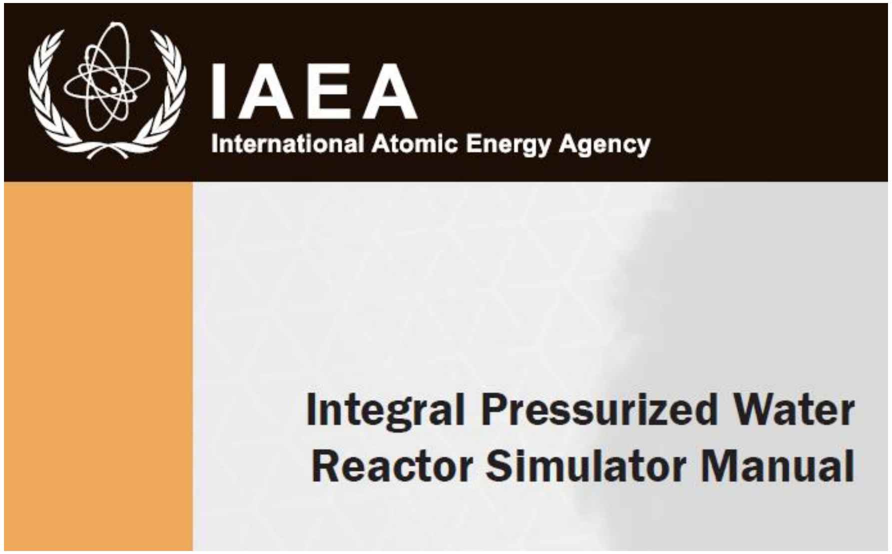
Normal Operation

- Power Reduction/Increase
- Normal Reactor Trip

Malfunction Transient Events

- Loss of Feedwater Flow
- Turbine Runback
- Large Steam Generator Tube Rupture (SGTR)
- Large Main Steam Line Break (MSLB)
- Steam Line Isolation
- Reactor Pressure Vessel Safety Valve Opening
- Reactor Coolant Pumps Trip
- …many others

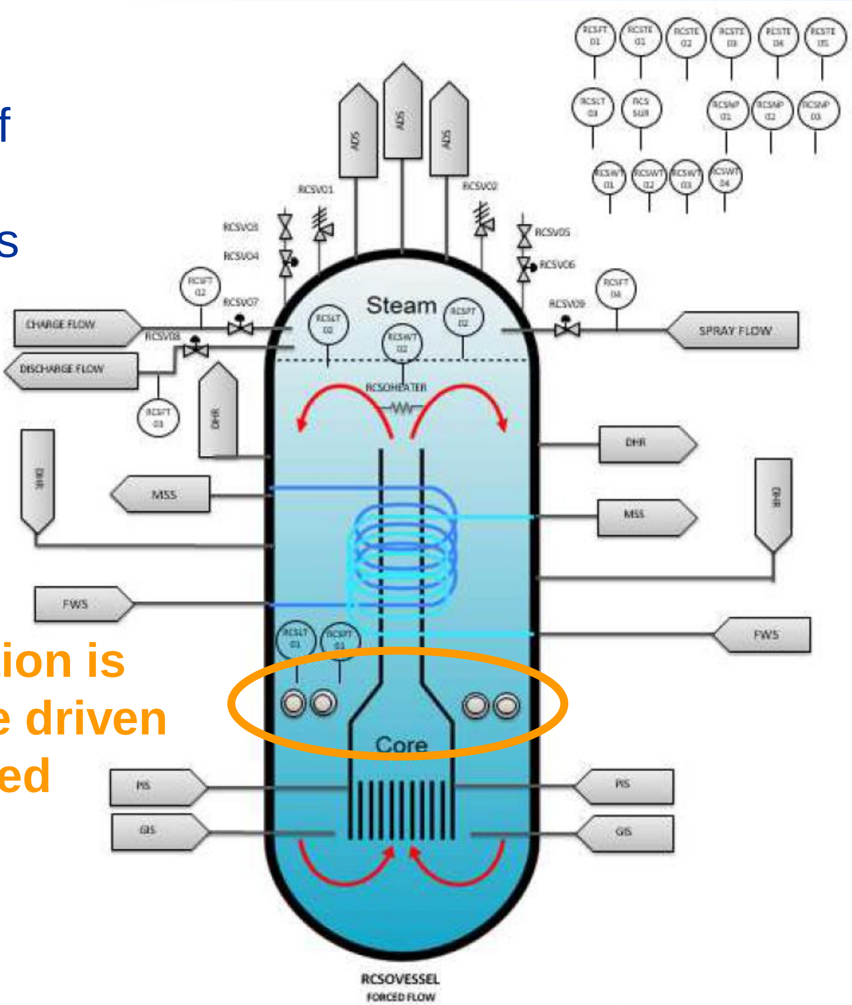
https://www.iaea.org/topics/nuclear-power-reactors/nuclear-reactor-simulators-for-education-and-training/integral-pressurized-water-reactor-simulator



Forced OR Natural Circulation

For each configuration, **6 I.C.'s** are available to start the simulation.

- 100% F.P. at beginning/middle/end of fuel cycle
- 0% power, various start-up conditions



If a forced circulation configuration is selected, the coolant flow will be driven by four horizontal pumps installed within the RPV above the core.

iPWR Systems

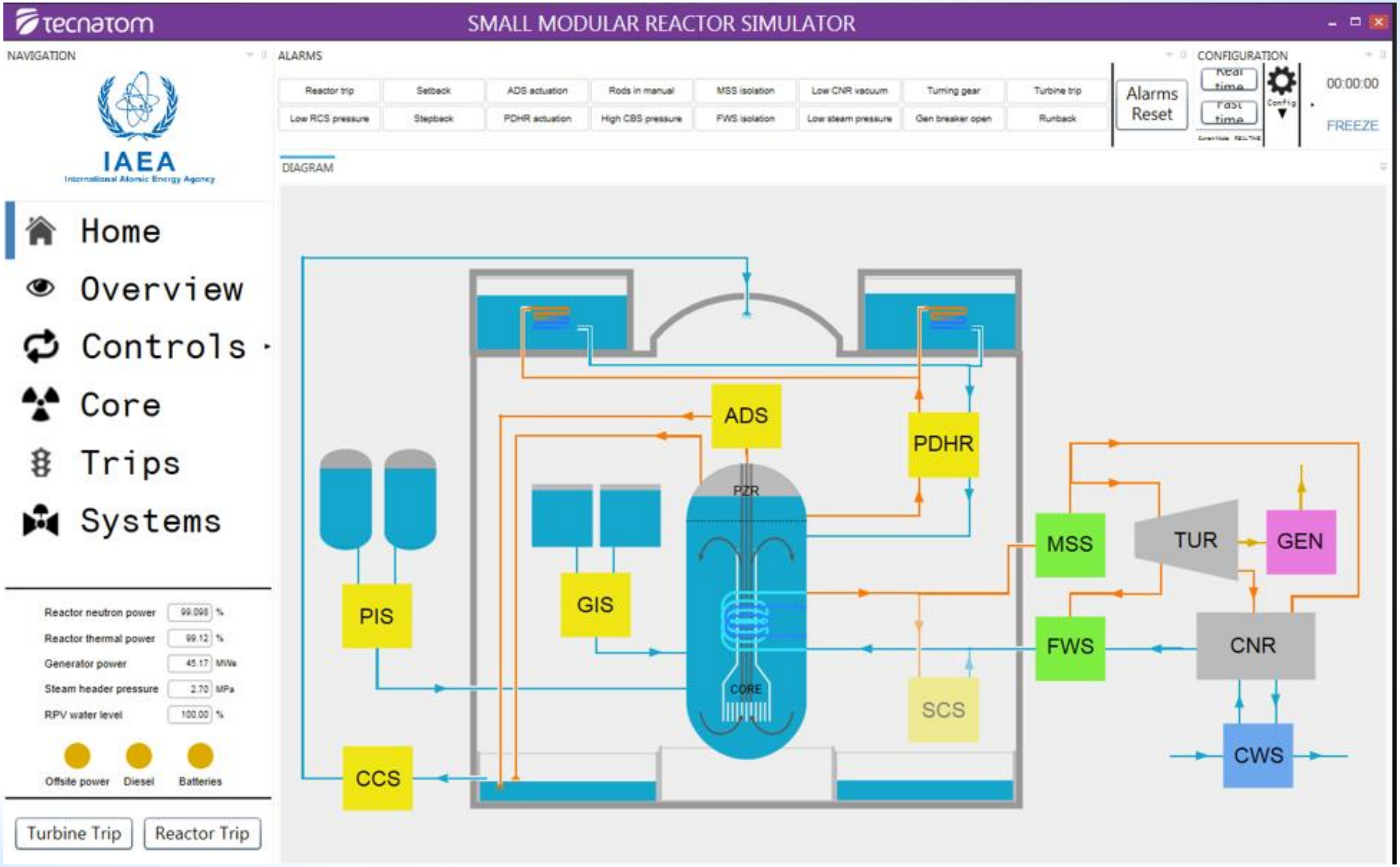
The iPWR simulator represents the **primary and balance of plant (BOP) systems** and behaviours. In order to simulate the whole operation, the following systems have been simulated:

(a) Reactor coolant system and reactor core (RCS);
(b) Main steam system (MSS);
(c) Feedwater system (FWS);
(d) Turbine system (TUR);
(e) Generator system (GEN);
(f) Condenser system (CNR);
(g) Circulating water system (CWS);
(h) Containment building system (CBS);
(i) Automatic depressurization system (ADS);
(j) Containment cooling system (CCS);
(k) Gravity driven water injection system (GIS);
(l) Pressure injection system (PIS);
(m) Passive decay heat removal system (PDHR);
(n) Protection and control system (PCS).

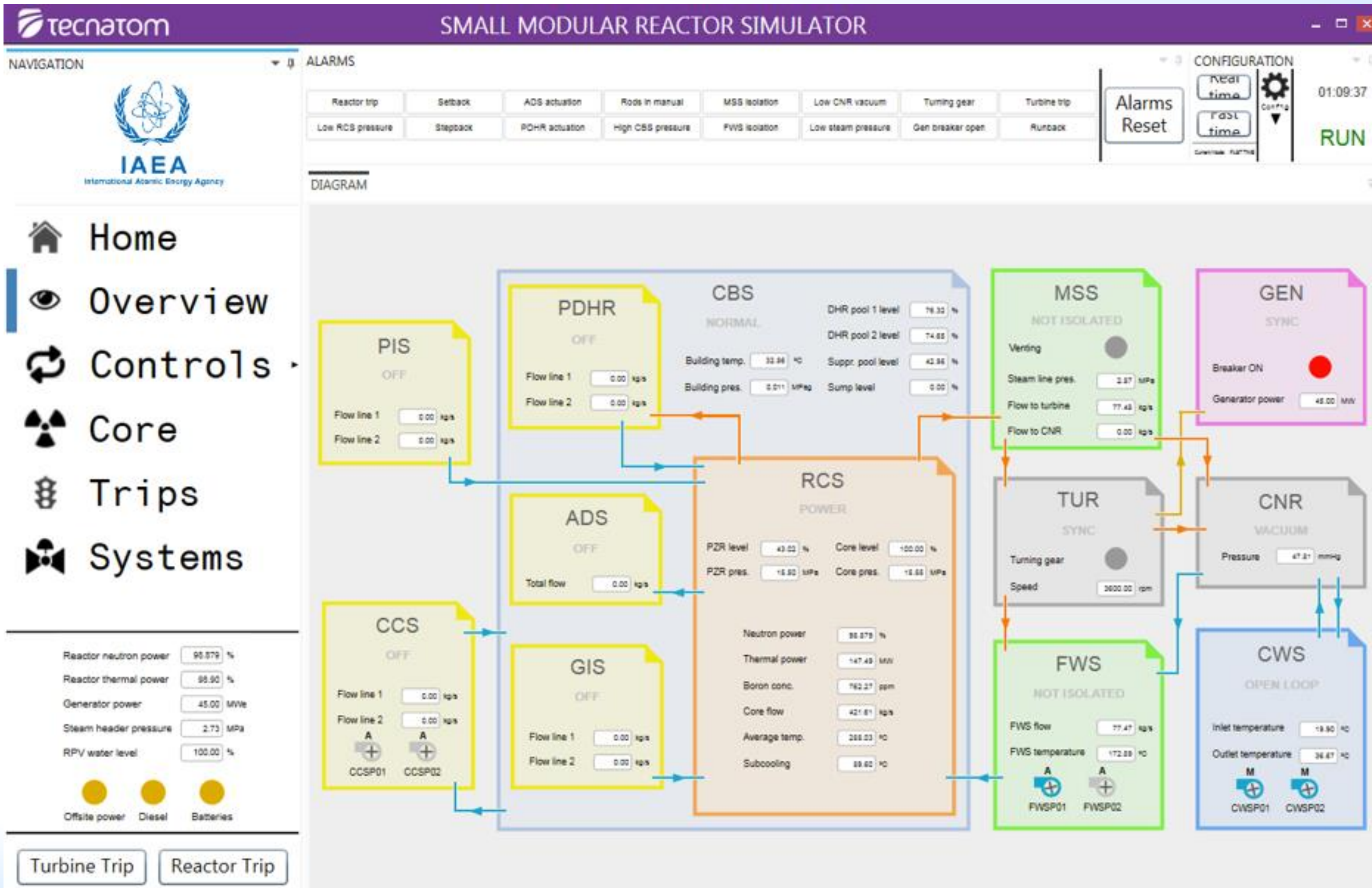
Reactor Trips (Rod Insertion):

a) Low pressure upper plenum (P < 11.0MPa)
b) Low level upper plenum (L < 5.0%)
c) Low flow downcomer (Q < Q=F(P))
d) High core outlet temperature (T < 340.0^{o}C)
e) High reactor neutron flux (Flux < 120%)
f) High log rate (SUR > 2. dpm)
g) High pressure upper plenum (P > 16.4 MPa)
h) FW pumps trip
i) ADS actuation
j) Seismic Event
k) Manual scram

iPWR – Home Screen



iPWR – Overview Screen



iPWR - Available Tutorials

IAEA 60 Years
Atoms for Peace and Development

Path Forward …

… in the past some simulators were donated, some funded from IAEA-RB (the old ones and iPWR) …

- MS interest in increasing
- More simulators are desired, **in particular SMRs**
- Old simulators need updating (OS, newer designs, modern GUI, etc.)
- **We have very limited funds!**

→ Starting from existing MS capabilities (training simulators) and donate (modified) version

Pressurized Water Reactor (PWR) Simulators

- ❑ Gen II Pressurized Water Reactor (PWR)
- ❑ 2-Loop Large PWR (Korean-OPR 1000)
- ❑ Russian-type PWR (WWER-1000)
- ❑ Advanced Passive PWR (AP-600)
- ❑ Integral Pressurized Water Reactor (SMR)

Boiling Water Reactor (BWRs) Simulators

- ❑ Advanced Boiling Water Reactor (BWR)
- ❑ Advanced Passive BWR (ESBWR)

Pressurized Heavy Water Reactor (PHWR)

- ❑ Conventional PHWR
- ❑ Advanced PHWR (Candu-6)

Part-Task Simulator

- ❑ Micro-Physics Simulator (Lite)

Under Development

- ❑ Sodium Cooled Fast Reactor (SFR)
- ❑ High Temperature Gas Cooled Reactor (HTGR)

Thank you!