



**IAEA**

International Atomic Energy Agency  
*Atoms for Peace and Development*

# IAEA Activities in the Advanced LWR Project of Interest to SMRs: ARIS, Training Simulators and Reactor Technology Assessment

T. Jevremovic, Matthias Krause

IAEA - NPTDS

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**2<sup>nd</sup> Meeting of the Technical Working Group for Small and  
Medium-sized or Modular Reactor (TWG-SMR)**

**8-11 July 2019**



**IAEA**

International Atomic Energy Agency  
*Atoms for Peace and Development*



Technology development for water cooled reactors

# OUTLINE

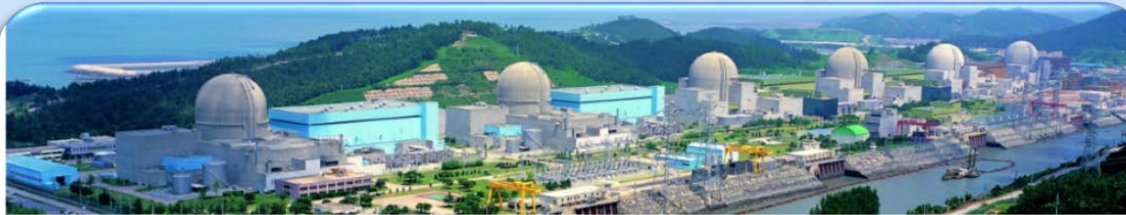
- 1. WCR Team Activities**
- 2. Data Bases: ARIS, THERPRO**
- 3. Educational Simulators and eLearning Modules**
- 4. Reactor Technology Assessment**
- 5. Summary and Outlook**



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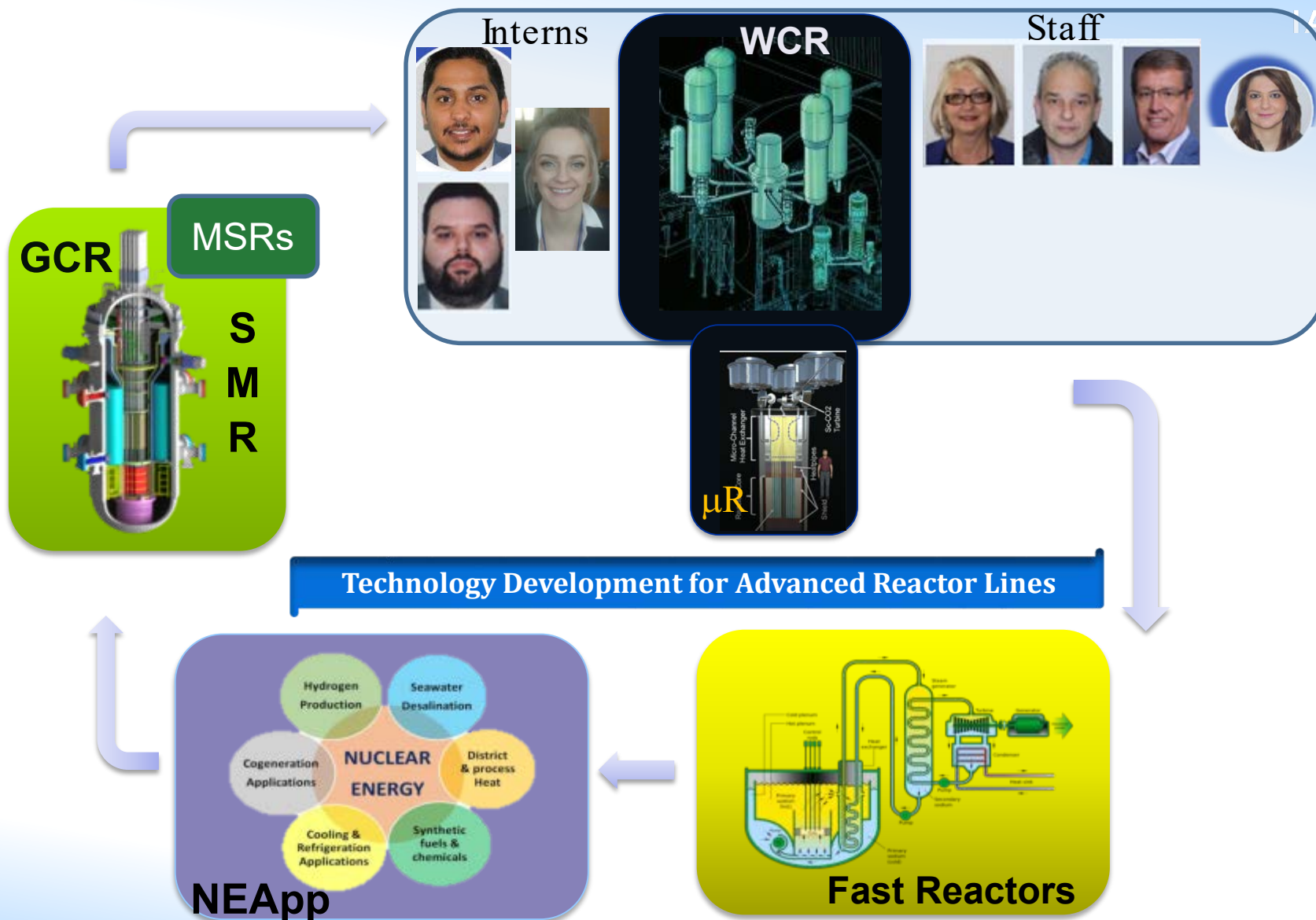


**Technology development for water cooled reactors**

# OUTLINE

- 1. WCR Team Activities**
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# 2019 WCR Team Members



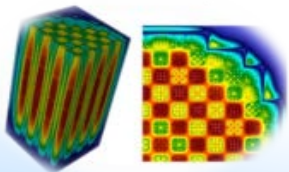
# International Cooperation and Information Exchange

## Knowledge Preservation



### Technology development for water cooled reactors

Modelling & Simulations



Development of Methodologies



Education & Training



Data Bases & Educational Toolkits



Technology Support Safety Systems



# Water Cooled Reactors: Key Activities

## Information Exchange

- Technical Meetings and publications on topics of programme mandate
- ARIS and THERPRO data bases
- CRPs and publications
- Education courses and corresponding course booklets with hands-on exercises and train-the-trainer approach to human capacity development in Member States

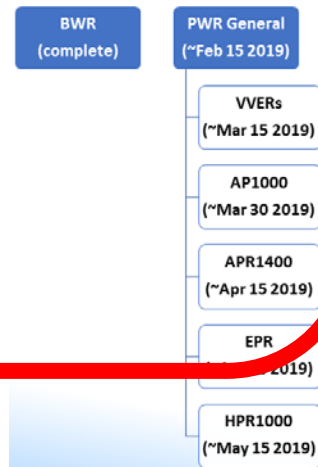


## Knowledge Preservation

- PC based basic principle simulators learning aids
- Education courses booklets for standardized teaching and instructions on learning-by-doing practices with simulators

## Education and Training

- 10 PC based basic principle simulators in supporting education and training courses on physics and technology of WCRs in Member States
- Joint ICTP-IAEA Courses on Scientific Novelties in the Phenomenology of Severe Accidents in Water Cooled Reactors
- eLearning tools



## Modelling and Simulations

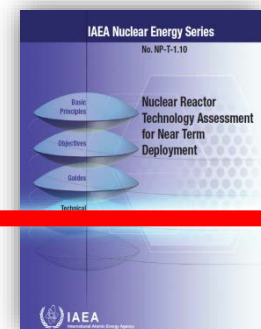
- CRPs on simulation codes for NPP designs and severe accidents
- Technical Meetings on severe accidents modelling and simulations codes, spent fuel pools and SAMG-D toolkit

## Technology Support

- CRPs on SCWRs technology development, multi-unit PSA, pipe failure rates estimates for advanced WCRs...

## Development of Methodologies

- Reactor Technology Assessment (RTA): Toolkit, interregional and national workshops and training courses, new NES





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Technology development for water cooled reactors

# OUTLINE

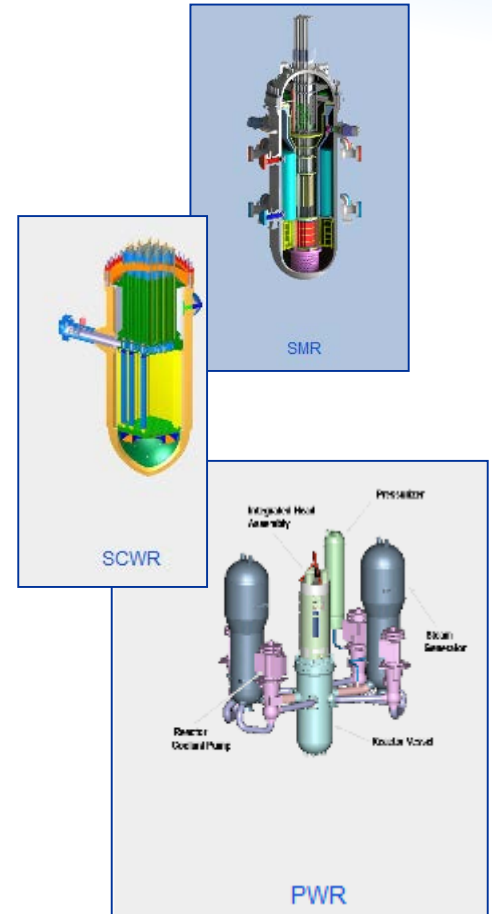
1. WCR Team Activities
2. **Data Bases: ARIS, THERPRO**
3. Educational Simulators and eLearning Modules
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# What is ARIS?

<https://aris.iaea.org/>

## Advanced Reactor

## Information System



# General Scope of Information

## The IAEA Advanced Reactors Information System (ARIS)



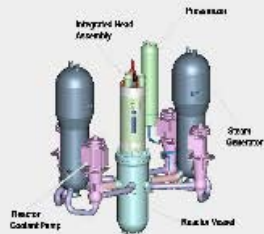
Member States interested in having ready access to the most up-to-date information about all available NPP designs, and important development trends.

ARIS is web-accessible database that provides balanced, comprehensive and up-to-date information about advanced NPP designs and concepts: **reactors of all sizes and all types from evolutionary NPPs for near term deployment, to innovative concepts still under development.**

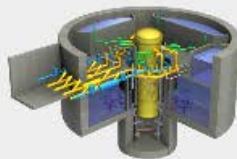
# All Reactor Types

## ADVANCED REACTORS

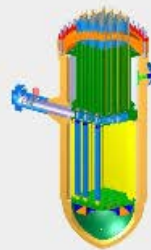
### WATER COOLED TECHNOLOGY



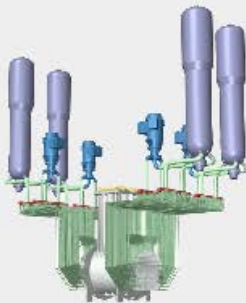
PWR



BWR



SCWR

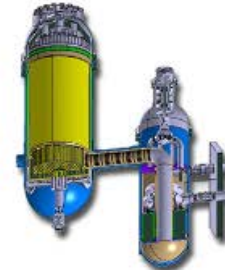


HWR



iPWR

### GAS COOLED TECHNOLOGY

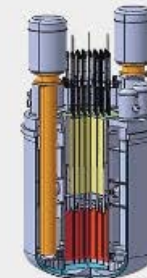


GCR

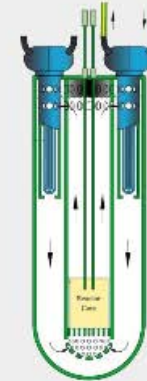


GFR

### MOLTEN METAL COOLED TECHNOLOGY

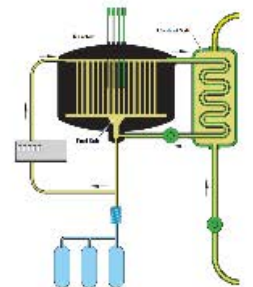


SFR

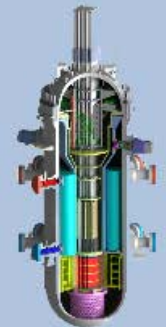


LFR

### MOLTEN SALT COOLED TECHNOLOGY



MSR



SMR

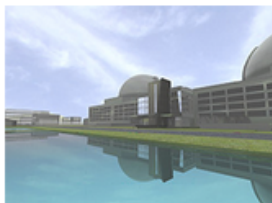
Updates

# BACKGROUND ON ARIS DATABASE

## ARIS

### The Database on Advanced Nuclear Power Reactors

The Advanced Reactor Information System (ARIS) is a database designed and maintained by the IAEA's Nuclear Power Technology Development Section (NPTDS) since 2009. The most important content of ARIS are the design descriptions of evolutionary and innovative advanced nuclear reactors. ARIS enables users to easily get an overview of the current reactor technologies being developed and deployed by giving people access to the designers' design descriptions. [Read more »](#)



## NPTDS

The goal of NPTDS (Nuclear Power Technology Development Section) is to foster information exchange and collaborative research in the area of advanced nuclear reactor technologies to ensure a sustainable, secure, stable and safe energy future for Member States.

[NPTDS Website](#)

## STATUS OF ADVANCED NUCLEAR REACTORS

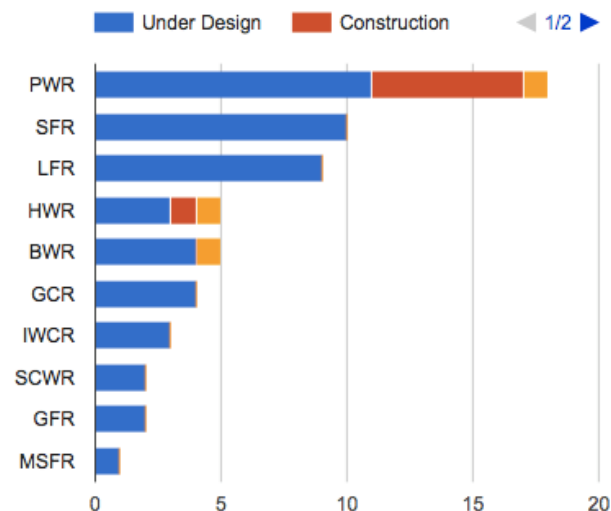
### Future of Nuclear Power

The IAEA anticipates that the global demand for electricity will continue to increase as a result of economic development aspirations and energy security concerns, and that expansion of nuclear power will continue at a slow but steady pace particularly in Asia and the Middle East.

### Advanced Designs

The ARIS database includes technical information about Advanced Reactor Designs that is provided by the responsible design organizations and/or reactor plant vendors. According to the definitions established by the IAEA, an advanced reactor design consists of both Evolutionary and Innovative reactor technologies. Evolutionary reactor designs are reactor designs that improve on existing designs through small or moderate modifications with a strong emphasis on maintaining proven design features to minimize technological risk. While innovative reactor designs incorporate radical changes in the use of materials and/or fuels, operating environments and conditions, and system configurations. Advanced reactors can be classified in terms of coolant, neutron spectrum, temperature or purpose. With regards to purpose, the reactors can be sorted in terms of experimental, demonstration or prototype, and commercial.

### Advanced Nuclear Power Plant Distribution by Reactor Types



# 40 SMR DESIGNS IN ARIS DATABASE



IAEA | ARIS Advanced Reactors Information System

Technical Data

Characteristics

Publications

Glossary

About ARIS

## Advanced Reactors Information System(ARIS)

Search Tabs

Overview General data Nuclear Steam Supply System Reactor Coolant System Reactor Core Core Materials Reactor Pressure Vessel

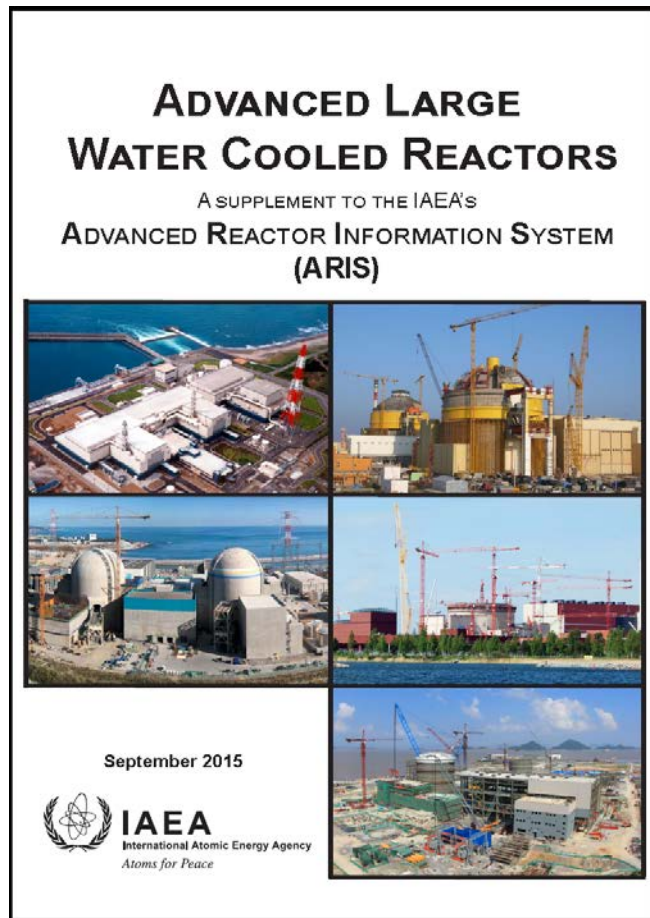
|         |                                      |                                  |                                     |                                    |                                    |                                    |                             |                                     |                              |                           |                             |                          |                                      |
|---------|--------------------------------------|----------------------------------|-------------------------------------|------------------------------------|------------------------------------|------------------------------------|-----------------------------|-------------------------------------|------------------------------|---------------------------|-----------------------------|--------------------------|--------------------------------------|
| Type    | <input type="radio"/> All            | <input type="radio"/> PWR        | <input type="radio"/> BWR           | <input type="radio"/> HWR          | <input type="radio"/> SCWR         | <input type="radio"/> iPWR         | <input type="radio"/> GCR   | <input type="radio"/> GFR           | <input type="radio"/> SFR    | <input type="radio"/> LFR | <input type="radio"/> MSR   | <input type="radio"/> FR | <input checked="" type="radio"/> SMR |
| Country | <input checked="" type="radio"/> All | <input type="radio"/> Canada     | <input type="radio"/> China         | <input type="radio"/> EU           | <input type="radio"/> France       | <input type="radio"/> India        | <input type="radio"/> Japan | <input type="radio"/> Rep. of Korea | <input type="radio"/> Russia | <input type="radio"/> USA | <input type="radio"/> Other |                          |                                      |
| Status  | <input checked="" type="radio"/> All | <input type="radio"/> On Hold    | <input type="radio"/> Under Design  | <input type="radio"/> Licensed     | <input type="radio"/> Construction | <input type="radio"/> In Operation |                             |                                     |                              |                           |                             |                          |                                      |
| Purpose | <input checked="" type="radio"/> All | <input type="radio"/> Commerical | <input type="radio"/> Demonstration | <input type="radio"/> Experimental | <input type="radio"/> Prototype    |                                    |                             |                                     |                              |                           |                             |                          |                                      |

(Click on acronym for more information)

### OVERVIEW

| Acronym                      | Full name                                                          | Design Org.                                                                | Coolant                     | Moderator    | Design Status     | Country | Type |
|------------------------------|--------------------------------------------------------------------|----------------------------------------------------------------------------|-----------------------------|--------------|-------------------|---------|------|
| <a href="#">4S</a>           | Super-Safe, Small and Simple Reactor                               | <a href="#">Toshiba</a>                                                    | Sodium                      | No Moderator | Under Design      | Japan   | SFR  |
| <a href="#">AHWR</a>         | Advanced Heavy Water Reactor                                       | <a href="#">BARC</a>                                                       | Light Water                 | Heavy Water  | Under Design      | India   | HWR  |
| <a href="#">ALFRED</a>       | Advanced Lead Fast Reactor European Demonstrator                   | Ansaldo Nucleare                                                           | Lead                        | No Moderator | Under Design      | EU      | LFR  |
| <a href="#">ALLEGRO</a>      | ALLEGRO                                                            | EURATOM                                                                    | Helium                      | No Moderator | Under Design      | EU      | GFR  |
| <a href="#">ASTRID</a>       | Advanced Sodium Technological Reactor for Industrial Demonstration | CEA                                                                        | Sodium                      | No Moderator | Under Design      | France  | SFR  |
| <a href="#">BREST-OD-300</a> | BREST-OD-300                                                       | RDPIE                                                                      | Lead                        | No Moderator | Under Design      | Russia  | LFR  |
| <a href="#">CFR-600</a>      | China Fast Reactor 600                                             | China Institute of Atomic Energy                                           | Sodium                      | No Moderator | Conceptual Design | China   | SFR  |
| <a href="#">CLEAR-I</a>      | China LEAd-based Research Reactor                                  | Institute of Nuclear Energy Safety Technology, Chinese Academy of Sciences | Lead Bismuth Eutectic alloy | No Moderator | Conceptual Design | China   | LFR  |
| <a href="#">ELECTRA</a>      | European Lead Cooled Training Reactor                              | KTH                                                                        | Lead                        | No Moderator | Under Design      | Sweden  | LFR  |
| <a href="#">ELFR</a>         | European Lead Fast Reactor                                         | Ansaldo Nucleare                                                           | Lead                        | No Moderator | Conceptual Design | EU      | LFR  |

# Current Booklets



Large WCR and FR are published as-needed

SMR Booklet is published every 2 years



## Advances in Small Modular Reactor Technology Developments

A Supplement to:  
IAEA Advanced Reactors Information System (ARIS)  
2018 Edition



# New ARIS Design & Inputs for Booklet

[Representative Picture of Reactor]

Reactor Units in PRIS (if applicable):

| Country | Site Name | No. of Units<br>(operating / under construction) |
|---------|-----------|--------------------------------------------------|
|         |           |                                                  |
|         |           |                                                  |
|         |           |                                                  |
|         |           |                                                  |

Status Report – **SHORT REACTOR NAME (Designer/Vendor)**

Country of Origin

DATE (Y/M/D)

This reactor design is an evolution from the previous **SHORT REACTOR NAME**, of which # units are operating in [LIST OF COUNTRIES and link to PRIS], **OR** of which # units are under construction in [LIST OF COUNTRIES and link to PRIS], **OR** which is described in [link to relevant other ARIS Status Report], **OR** is a new concept with a projected earliest deployment (start of construction) time of **YEAR**.

The reference plant is [Name of Site and link to PRIS page] and has a net power output of **xxx MWe** [or **xxx MWth** if primary application is non-electric].

## INTRODUCTION

*250-300 words describing the reactor's distinguishing features, target application(s), and overall design philosophy. This will also appear in the ARIS Booklet(s) that are periodically published in hardcopy. DO NOT RESIZE TEXT BOX (~1000 characters 12-pt)*

Indicate which booklet(s): ☐ Large WCR ☐ SMR ☐ FR

## Development Milestones (example below is for illustration only)

|      |                                                             |
|------|-------------------------------------------------------------|
| 2010 | Previous reactor version – Start of design (changes)        |
| 2015 | Concept design completed                                    |
| 2016 | Start of pre-licencing vendor design review (in country x)  |
| 2019 | Engineering design complete                                 |
| 2020 | Secure necessary licenses (in country x)                    |
| 2022 | Start construction of a first full-scale NPP (in country x) |
| 2025 | Commercial operation                                        |

Design organization or vendor company (e-mail contact):

Links (www...) to designer/vendor homepage:

Detailed Design Description:

Most Recent Licensing Application Support Document, e.g.:

# THERPRO DATABASE

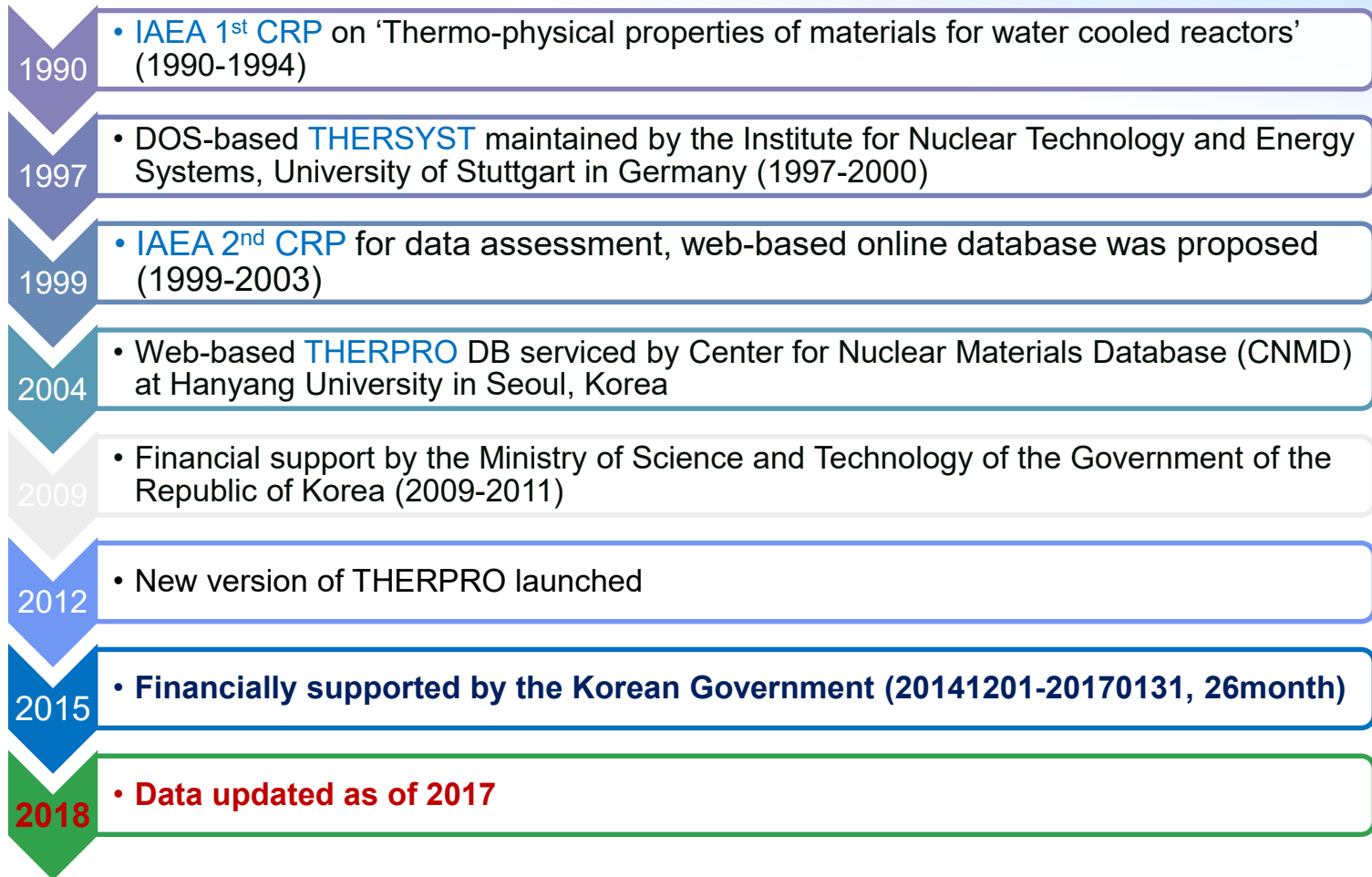


THERPRO is a web-based on-line database (<http://therpro.iaea.org>), providing **thermo-physical material properties** data to the registered users in IAEA Member States since 2009

A screenshot of the THERPRO database website. The header includes the IAEA THERPRO logo and navigation links: Home, Log-in, Registration, Help, Contact Us. Below the header is a blue navigation bar with links: About THERPRO, Basic Search, Power Search, Press Room, DB Library, and Link. The main content area features a large "THERPRO" title, the text "CNMD Center for Nuclear Materials Data Base" and "IAEA International Atomic Energy Agency", and a "Search" button. There are three main sections: "News" with a link to "Data newly updated 2018-06-25 09:43", "Bulletin" with a link to "Data collection 2018-05-23 10:21", and "Announcement" with a link to "Final Announcement for 2011 TM on T... 2011-10-30 15:26". The footer includes the IAEA logo, the Ministry of Education, Science and Technology logo, and the Hanyang University logo, along with a copyright notice: "IAEA Designated Center for Nuclear Materials Properties Database Management Copyright © 2010 IAEA Therpro Hanyang University. All Right Reserved."

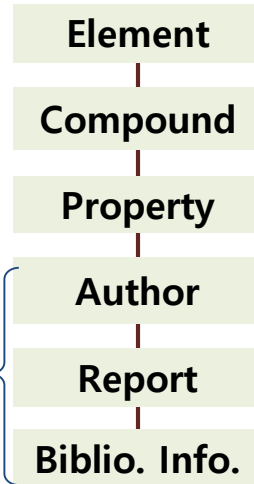
**11,000 property data set for ~1,600 materials**

# HISTORY OF THERPRO DATABASE DEVELOPMENT



# THERPRO DATABASE STRUCTURE

Database platform

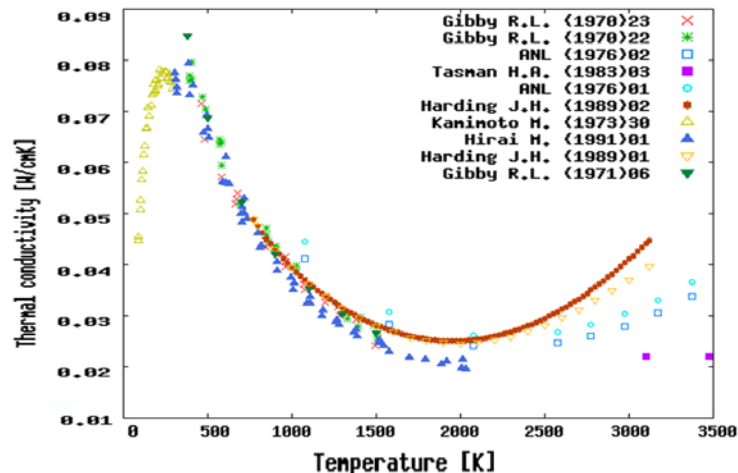


THERPRO database hierarchical structure consists of several levels: element, compound, property, author, report and bibliography.

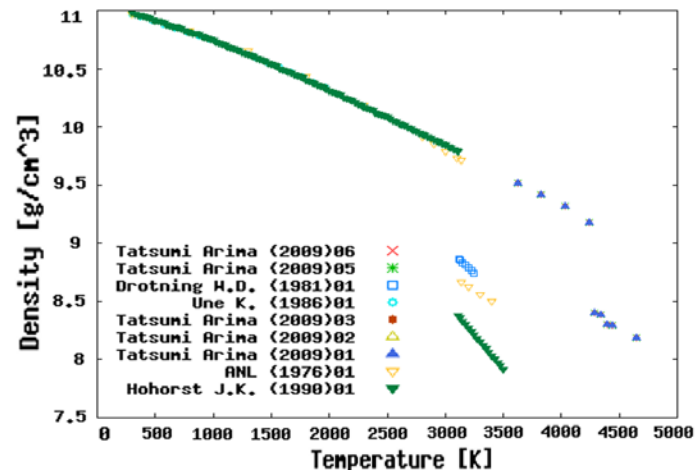
## Compiled Properties

- Thermal conductivity
- Thermal diffusivity
- Specific heat capacity
- Enthalpy
- Density
- Linear thermal expansion
- Linear expansion coefficient
- Volumetric thermal expansion
- Volumetric expansion coefficient
- Electric resistivity
- Lorentz number
- Absorptance
- Reflectance
- Refractive index
- Emittance
- Extinction coefficient
- Transmittance

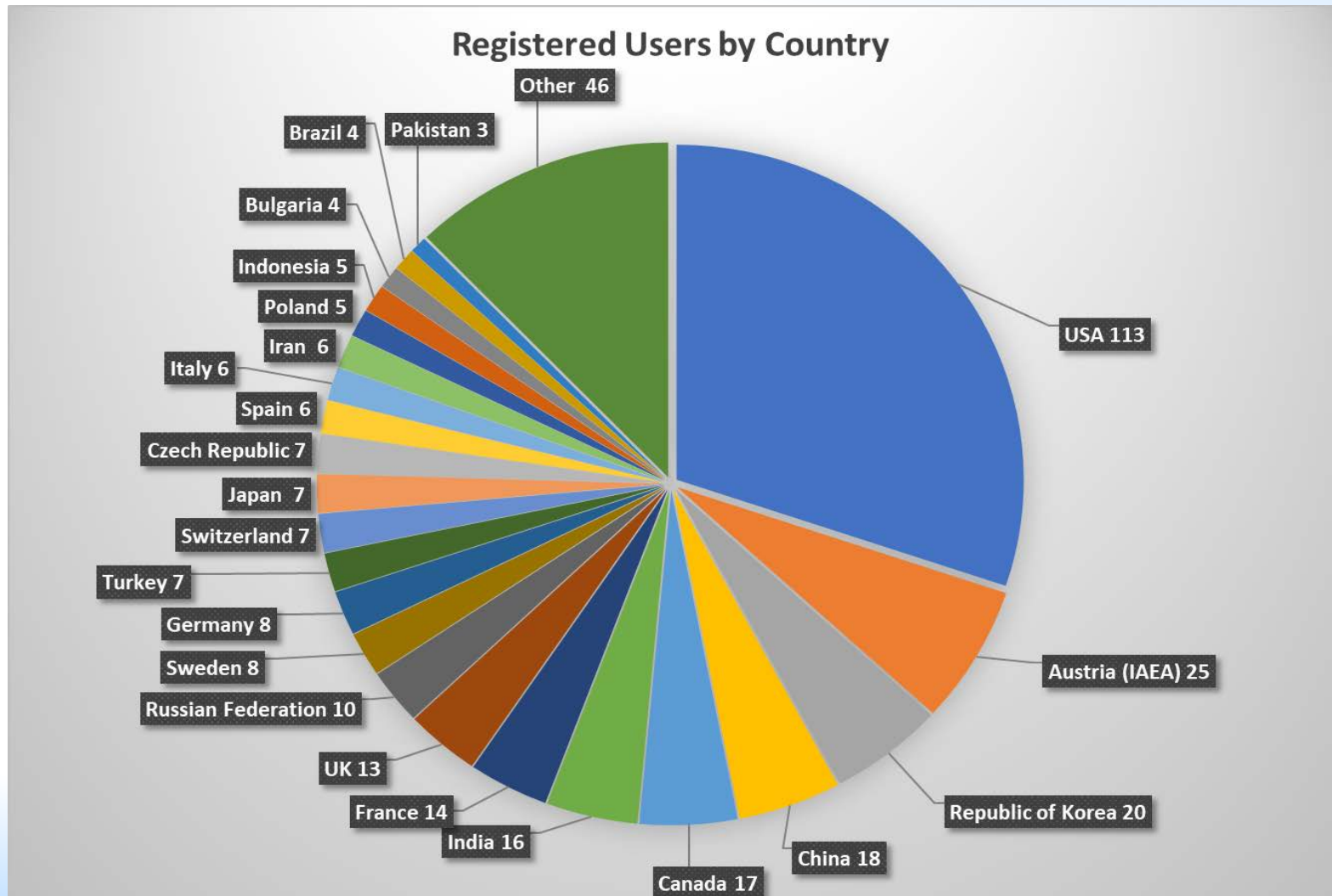
Thermal conductivity of  $\text{UO}_2$



Density of  $\text{UO}_2$



# THERPRO DATABASE USERS





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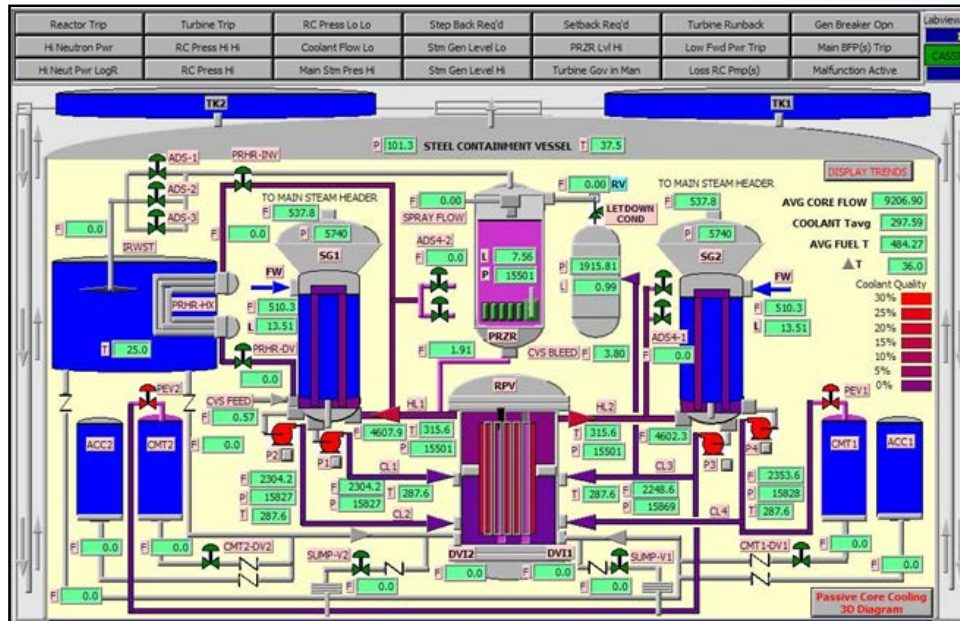
Technology development for water cooled reactors

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1. WCR Team Activities
2. Data Bases: ARIS, THERPRO
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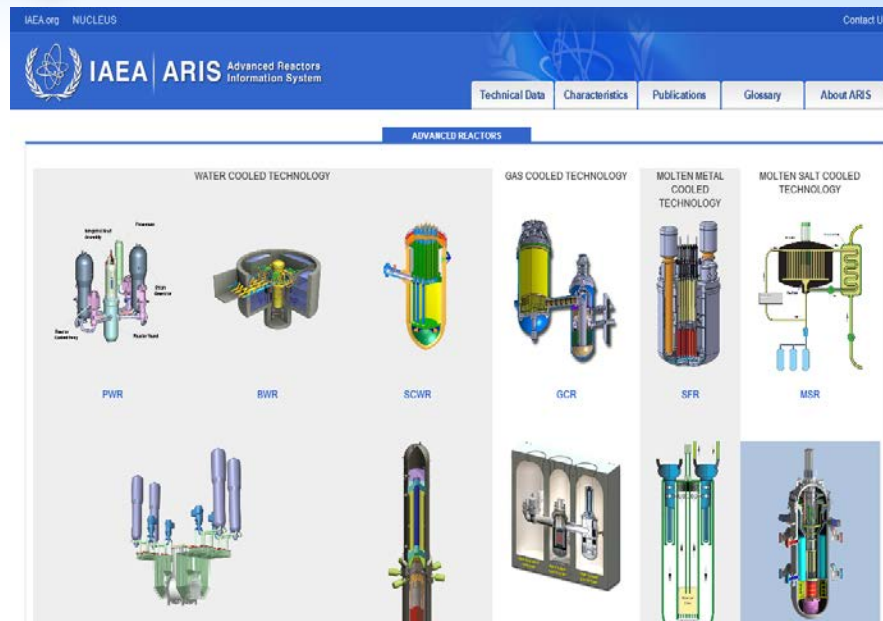
# Understanding Technology IAEA Tools & Training Courses

## Advanced PHWR Simulator



**IAEA approach: basic principle  
simulators that** provide a thorough learning about general concepts and physical processes in nuclear power plant:

- Operational characteristics
- Reactivity control systems
- Safety systems
- Responses to transients and accidents



**IAEA ARIS data base** provide detailed descriptions about advanced reactor concepts including all reactor designs:

- PWR
- BWR
- SCWR
- PHWR
- VVER
- SMR
- MSR
- FR

# Application of Basic Principle Simulators

## IAEA 10 Basic Principle Simulators



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



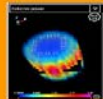
**To learn BUT not to use to assess technologies**



## Technology development for water cooled reactors

### Human Resource Development and Capacity Building in Member States Active Learning Through Education and Training Courses on Various Topics and with the Use of PC Based Basic Simulators in Understanding Physics and Technology of WCRs/FRs/HTGRs

#### IAEA's basic principle Simulators:



Simulate nuclear power plants' operation and responses to various inputs (transients, accidents) with illustrative screens are a state-of-the-art learning tool

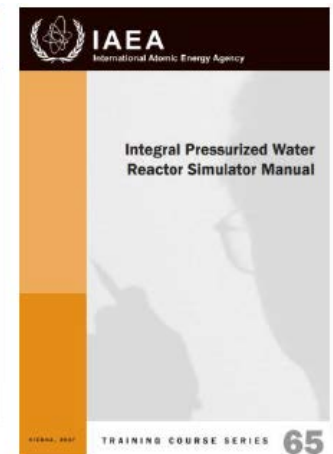
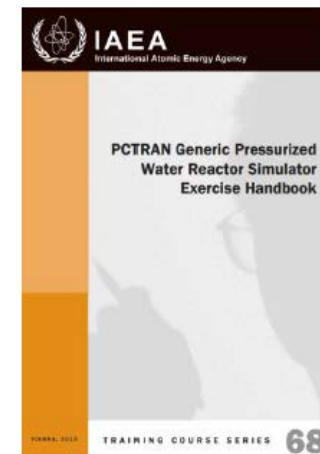


Designed to provide insight and understanding of the general design and operational characteristics of various power reactor systems



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

#### Manuals and Training Course Series



# IAEA Basic Principle Simulators

<https://www.iaea.org/topics/nuclear-power-reactors/nuclear-reactor-simulators-for-education-and-training>

## Pressurized Water Reactor (PWR) Simulators

- PCTTRAN: Conventional Two-Loop Pressurized Water Reactor
- Advanced PWR: Two-Loop Large PWR (Korean-OPR 1000)
- Russian-type PWR (VVER-1000)
- Advanced Passive PWR (AP-600)
- **Integral Pressurized Water Reactor (SMR)**

## Boiling Water Reactor (BWRs) Simulators

- Conventional Boiling Water Reactor with Active Safety Systems (BWR)
- Advanced BWR with Passive Safety Systems (ESBWR)

## Pressurized Heavy Water Reactor (PHWR)

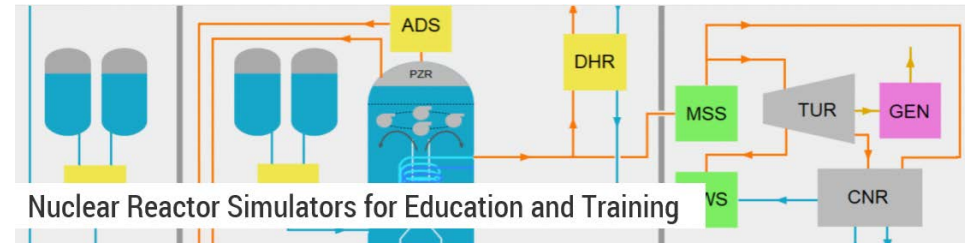
- Conventional Pressurized Heavy Water Reactor (PHWR)
- Advanced PHWR (ACR-700)

## Part-Task Simulator

- Micro-Physics Nuclear Reactor Simulator

## Under Development

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



## How to Obtain These Simulators

These simulators, including the associated documentation, are distributed at no cost to interested parties in IAEA Member States. Furthermore, the IAEA sponsors training courses and workshops on a regular basis, and would also be willing to support additional training events on this topic at the request of Member States.

Kindly follow these simple steps in order to obtain the complete suite of IAEA PC-Based Simulators:

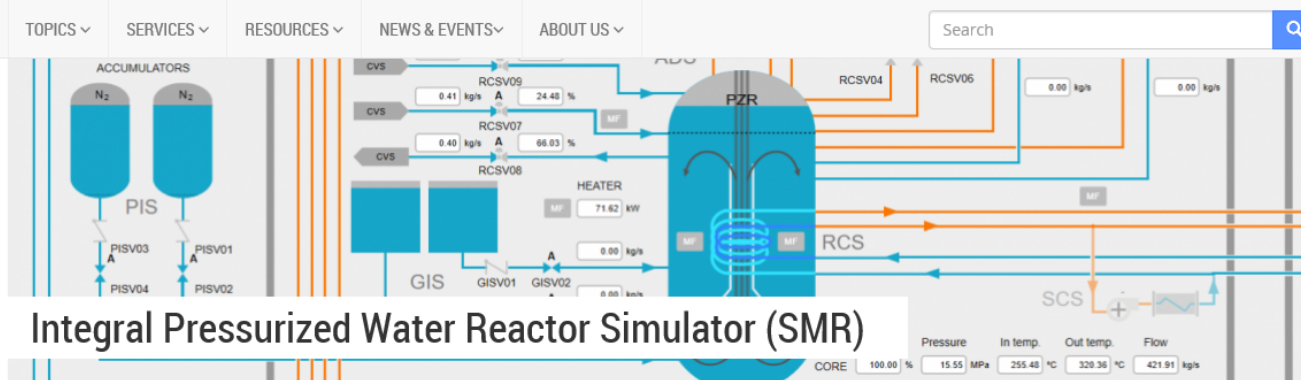
**Step 1:** Create a Nucleus login ID by registering on the [IAEA's Nucleus website](#). This is necessary in order to obtain access to our SharePoint website, where all the simulators are hosted.

**Step 2:** Download and fill out this [simulator request form](#).

**Step 3:** Scan and send the completed form to the competent official authority (Ministry of Foreign Affairs, National Atomic Energy Authority, or to the applicant's Member State Permanent Mission to the IAEA in Vienna, Austria) for their approval and signature (stamp).

After this the Permanent Mission will then forward the approved request to [Official Mail](#), the International Atomic Energy Agency, P.O. Box 100, Vienna International Centre, A-1400 Vienna, Austria. You will then receive an email from the IAEA with instructions on how to download all the simulators from our SharePoint website.

# SMR Basic Principle Simulator: Free Distribution



## Integral Pressurized Water Reactor Simulator (SMR)

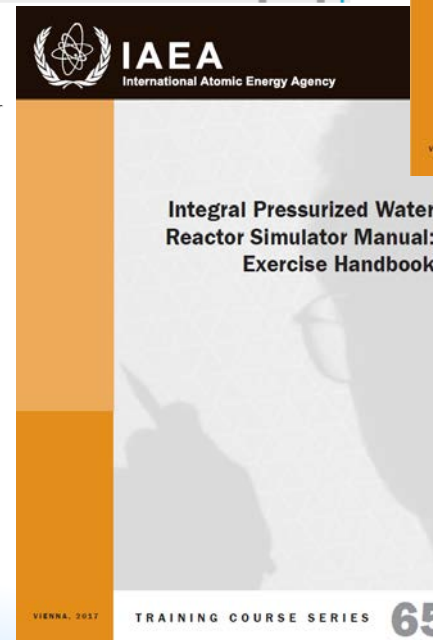
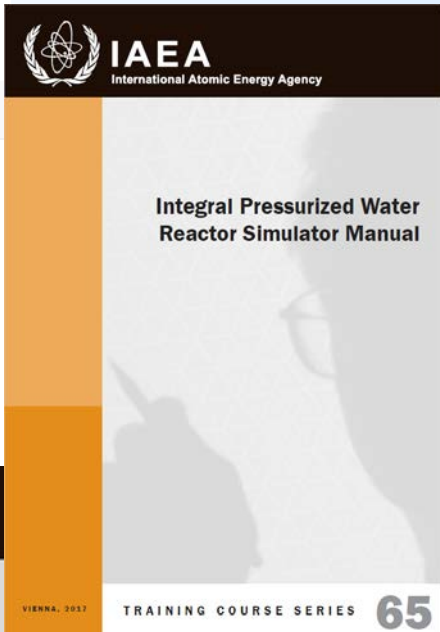
There is continuing global interest in the development of Small Modular Reactors (SMR). One type of SMR currently under the development in a number of countries is the integral Pressurized Water Reactor (iPWR). In this design, primary circuit components are placed within the reactor pressure vessel, eliminating the need for primary circuit pipework, with the intention of enhancing safety and reliability. This simulator is developed by Tecnom in 2017.

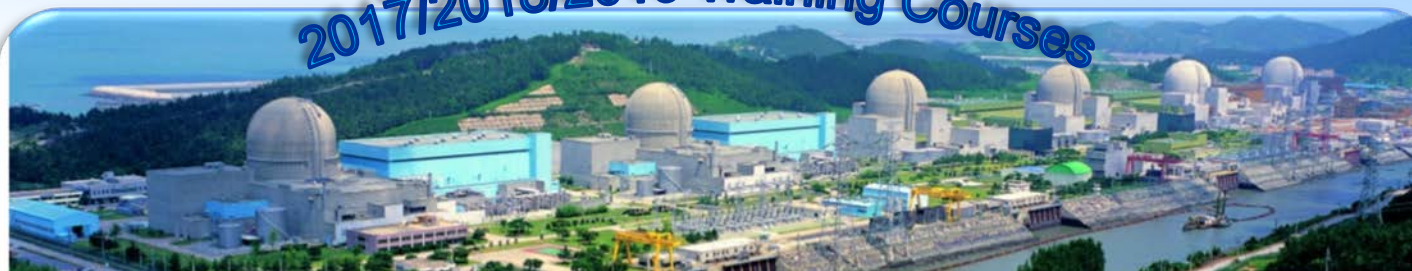
Details on the currently available SMR designs can be found in the [IAEA ARIS Database](#).

The iPWR simulator operational specifics are listed as follows:

- The simulator is designed to examine the primary and balance of plant (BOP) behaviors of the iPWR
- In order to simulate the operation under accident conditions, a variety of safety systems are implemented including Gravity Driven Water Injection System, Pressure Injection System, Passive Decay Heat Removal system (PDHR), 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 behavior can be observed during SBO until the reactor becomes stable.

Normal Operation





## Technology development for water cooled reactors

2018

1. Workshop on Small Modular Reactors Technology Assessment in Jordan [Video conference from VIC, Vienna to Amman, Jordan, 10 – 12 April, 2018]
2. Workshop on Reactor Technology Assessment Training for Large Water Cooled Reactors in Saudi Arabia [Riyadh, Saudi Arabia, 15 – 19 April, 2018]
3. Nuclear Infrastructure Training Course [Vienna, 2 - 11 May, 2018]
4. Interregional Training Course on Nuclear Power Plant Contract Specifications and Reactor Technology Assessment [Vienna, Austria, 8-12 October, 2018]
5. Reactor Technology Assessment: Testing the IAEA's Reactor Assessment Methodology (12 – 16 November, VIC, 2018)
6. Advanced WCRs: Physics, Technology, Passive Safety, and Basic Principle Simulators [Islamabad, Pakistan, 22 – 26 January, 2018]
7. Regional Training Course on Pressurized Water Reactor (PWR) Technology Using PC Based Basic Principle and GlassTop Nuclear Power Plant Simulators [Sharjah, UAE, 19 – 23 February, 2018]
8. National Training Workshop on Small Modular Reactors Technologies and the IAEA iPWR Basic Principle Simulator [Irbid, Jordan, 9 – 13 September, 2018]
9. JOINT ICTP-IAEA 1st COURSE ON SCIENTIFIC NOVELTIES IN THE PHENOMENOLOGY OF SEVERE ACCIDENTS IN WATER COOLED REACTORS [Trieste, Italy, 22 – 26 October, 2018]
10. Regional Training Workshop on Phenomenology and Numerical Simulations of Severe Accidents in Advanced WCRs [New Delhi, India, 3 – 7 December, 2018]



2017

|                                                                                                                                         |                                      |                                 |
|-----------------------------------------------------------------------------------------------------------------------------------------|--------------------------------------|---------------------------------|
| Pilot Training on WCR Technologies and Severe Accidents with Simulators                                                                 | Salt Lake City, USA<br>February 2017 | Okayama University, Japan       |
| IAEA/KAERI Regional Course on WCRs Technologies and Passive Systems: Competence Based-Approach with PC-Based Basic Principle Simulators | KAERI, RoK<br>September 2017         | TC, KAERI                       |
| Advanced WCRs: Physics, Technology, Passive Safety and Basic Principle Simulators                                                       | Islamabad, Pakistan<br>October 2017  | TC, Pakistan                    |
| Training Course on Reactor Technologies and Severe Accidents: Learning-by-Doing with PC Simulators                                      | Salt Lake City, USA<br>November 2017 | Okayama University, JAIF, Japan |
| Understanding Technology and Physics of WCRs with PC Simulators                                                                         | ICTP, Italy<br>November 2017         | ICTP, TC, NPTDS                 |
| IAEA/VINATOM National Training Course on PWRs Technologies and Passive Safety Systems                                                   | Hanoi, Vietnam<br>December 2017      | TC, VINATOM                     |

# 2019 Training Courses and Scientific Visits [TC support]



**17 – 27 February, 2019**  
**University of Sharjah, Sharjah, UAE**  
**Regional Training Course on PWR Technologies Using PC Based Basic Principle and GlasTop NPP Simulators**  
**[M. Krause]**

The purpose of the event is to provide a comprehensive training on physics and technology of PWRs using PC based basic principle simulators and the GlasTop simulators

2<sup>nd</sup> course on  
 June 24-28, 2019

Joint ICTP-IAEA  
 1st Course on  
 Scientific Novelties in  
 Phenomenology of Severe Accidents  
 in Water Cooled Reactors (WCRs)

22 - 26 October 2018  
 Trieste, Italy **[A. Miassoedov]**

**10 – 14 June, 2019**  
**VIC, Vienna**  
**Regional Training Course on RTA for SMRs**  
**[T. Jevremovic, F. Reitsma]**

**8 – 12 April, 2019**  
**Wuhan, China**  
**Regional Training Course on WCR Technologies and Educational Simulators**  
**[A. Miassoedov]**

The purpose of the event is to provide a comprehensive training on physics and technology of water cooled reactors using educational and training simulators and provide theoretical teaching about various advanced water cooled reactor technologies and design concepts with practical demonstrations of various operation conditions including extensive group exercises and projects designed to assure the understanding of presented concepts

**24 – 27 September, 2019**  
**Hanyang University, Seoul, Republic of Korea**  
**Regional Training Course on Science and Technology of Water Cooled Reactors and Introduction of Supercritical Water Cooled Reactor Concepts**  
**[T. Jevremovic]**

The purpose of the event is to provide a comprehensive training on physics and technology of evolutionary and innovative WCRs and introduce various conceptual designs of SCWRs

**15 – 19 April, 2019**  
**Beijing, China**  
**National Training Course on Hydrogen Management in Severe Accidents in WCRs**  
**[T. Jevremovic]**

The purpose of the event is to provide a comprehensive training on physics and technology of hydrogen generation, propagation, combustion and mitigation processes in WCRs with modern and state-of-the-art simulation tools

**9 – 13 September, 2019**  
**Raleigh, North Carolina, USA**  
**Regional Scientific Visit on the State of Current Knowledge of Advanced Nuclear Power Reactor Designs with Educational Tools Supporting Regional Human Capacity Development**  
**[T. Jevremovic]**

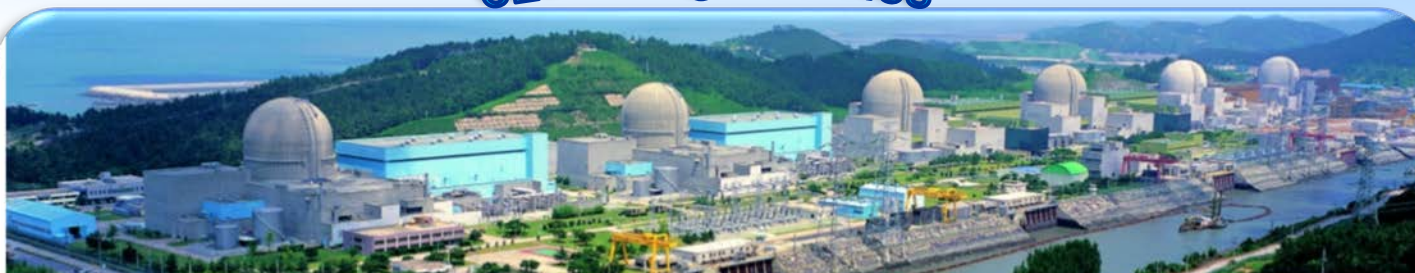
The purpose of the event is to provide a comprehensive overview on physics and technology of water cooled reactors through scientific visits of various facilities, technical tours, discussions and lectures on technology, simulation codes and plant simulators provided uniquely by the host institution

**9 – 13 September, 2019**  
**Beijing, China**  
**Regional Training Course on Science and Technology of Passive Safety Systems in WCRs**  
**[M. Krause]**

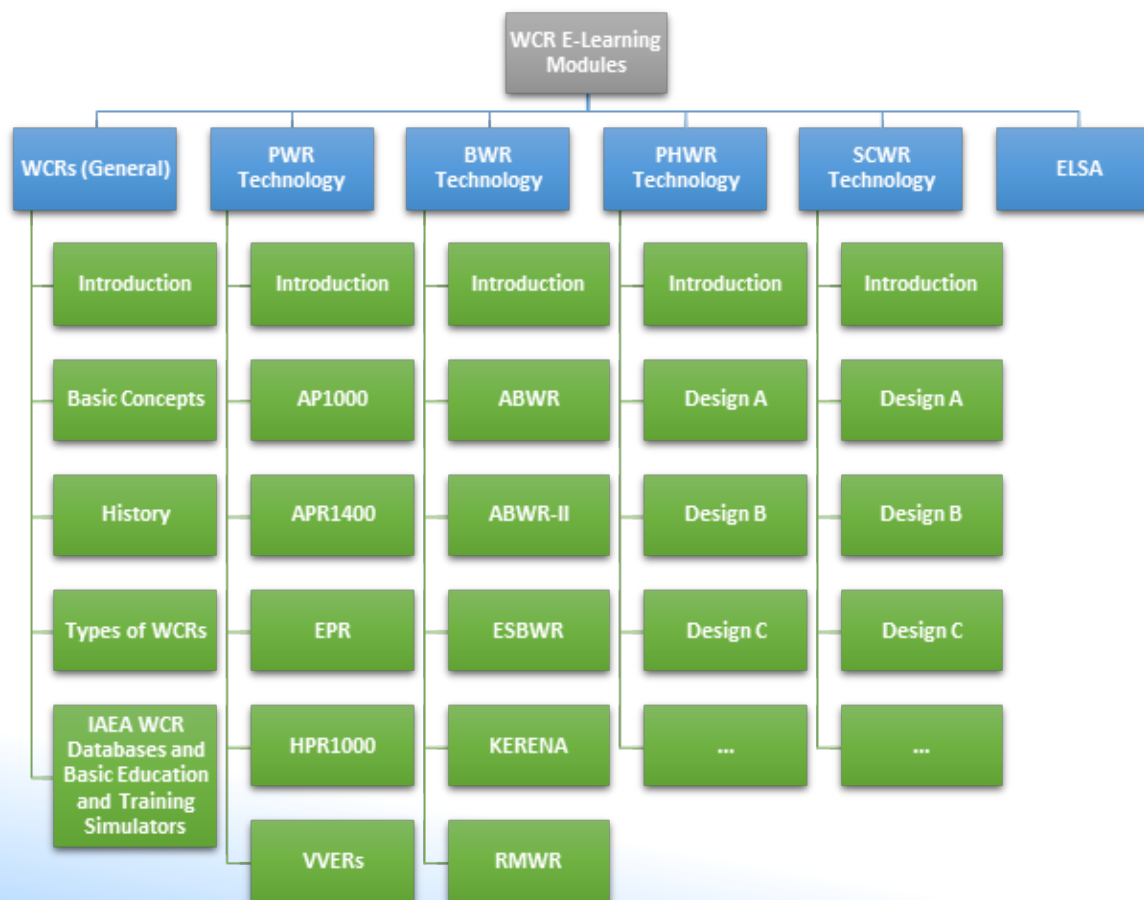
The purpose of the event is to provide a comprehensive training on physics and technology of passive safety system designs in evolutionary and innovative WCRs

**4 – 8 November, 2019**  
**State College, Texas, USA**  
**Regional Scientific Visit on the State of Current Knowledge of Advanced Nuclear Power Reactor Designs with Educational Tools Supporting Regional Human Capacity Development**  
**[M. Krause]**

The purpose of the event is to provide a comprehensive overview on physics and technology of water cooled reactors through scientific visits of various facilities, technical tours, discussions and lectures on technology, simulation codes and plant simulators provided uniquely by the host institution



## Technology development for water cooled reactors





# Technology development for water cooled reactors

## The IAEA Advanced Water Cooled Reactor E-Learning Module: Boiling Water Reactors



### Overview

The Advanced Water Cooled Reactor E-Learning Modules are developed as tools for education on various water cooled reactor technologies. The Boiling Water Reactor E-Learning Module is the first of a series of such modules, and consists of the following five submodules:

- Submodule 1: Introduction
- Submodule 2: Basic Concepts
- Submodule 3: History
- Submodule 4: Global Deployment
- Submodule 5: Advanced Designs

Each submodule includes multiple choice questions and a review quiz is included at the end of the module to reinforce learned information.

### Boiling Water Reactors

An Introduction to Basic Concepts, History, Global Deployment and Advanced Designs

E-learning Module

Prepared by:  
Nuclear Power Technology Development Section - Water Cooled Reactor Team

### Submodule 1: Introduction

This submodule introduces the topics which are covered in the module as well as describes how to navigate, use, and interact with the module. There are several buttons for navigation and which can be used to read information aloud. It also introduces Walter!



My name is Walter and I provide supplementary information to users to enhance learning with the Boiling Water Reactor Module!



### Submodule 2: Basic Concepts

This submodule provides necessary background information on boiling water reactor technology. This information includes a basic description of basic nuclear reactor physics, major boiling water reactor systems and components, and a description of advanced reactor technologies.

#### Basic Concepts: Neutron Energy

When a thermal fission occurs, resultant neutrons travel at high speed with around 2 MeV of kinetic energy. These are called fast neutrons. In BWRs, neutrons are moderated, or slowed down, by elastic collisions with hydrogen and oxygen nuclei in water. This is because BWRs use thermal neutrons, which have energies around 0.025 eV.



#### Basic Concepts: Advanced Reactors

- Advanced reactor designs include both evolutionary and innovative reactor technologies.
- Evolutionary designs improve on existing designs through small or moderate modifications with a strong emphasis on maintaining proven design features to minimize technological risk.
- Innovative designs incorporate radical changes in the use of materials and/or fuels, operating environment and conditions, and system configurations.

More information on advanced reactors can be found at: [http://www.iaea.org/infocentre/newsroom/news/2011/01/20110120\\_01.html](http://www.iaea.org/infocentre/newsroom/news/2011/01/20110120_01.html)



### Submodule 3: History

This submodule describes the history of boiling water reactor technology. This includes a description of initial prototypes, summaries of major reactor and containment designs, and discusses major developments.

#### History: BWR/1

Model: BWR/1  
First Commercial Operation: 1962  
Containment: Dry

Developments:

- Initial commercial size BWR
- Dual cycle before driving steam is generated in both the reactor and an external heat exchanger

Example: Dresden 1, USA



#### History: ABWR Containment

The ABWR containment is much smaller than the Mark III containment due to elimination of recirculation loops.

The structure is a reinforced concrete containment vessel, consisting of reinforced concrete with a steel liner.



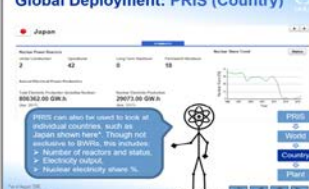
Dry → Mark I → Mark II → Mark III → ABWR → ESBWR

### Submodule 4: Global Deployment

This submodule describes the global deployment of boiling water reactors, including advanced technologies. This submodule details the relevant information which can be found on two IAEA databases: the Power Reactor Information System (PRIS) [<https://pris.iaea.org/PRIS/home.aspx>] and the Advanced Reactors Information System (ARIS) [<https://aris.iaea.org/>].

#### Global Deployment: PRIS (Country)

Japan



PRIS can also be used to look at individual countries, such as Japan shown here. Though not exclusive to BWRs, this includes:

- Number of reactors and status
- Electricity output
- Reactor electricity share %

#### Global Deployment: ARIS (Overview)

There are two main advanced BWR designs, of which the ABWR is the only operating advanced BWR. Users can take a closer look to see what specific design information is provided in ARIS.



### Submodule 5: Advanced Designs

This submodule details technical information for each of the five\* advanced boiling water reactor technologies included on the ARIS database. The description of each includes an overview of the design, the reactor core, the reactor coolant system, safety systems, and other main features.

#### ABWR: Reactor Core

Technical data:

- Core height: 3.81 m
- Core diameter: 5.183 m
- Average fuel power density: 25.0 kW/kg(U)
- Fuel material: UO<sub>2</sub>
- Outer diameter of fuel rods: 19.3 mm
- Rod array of a fuel assembly: 10 x 10
- Number of fuel assemblies: 872
- Fuel cycle length: 24 months



Characteristics:

- Electromechanical Prime Mover Control Rod Drive (PMCRD)
- Advanced control room and multiplexed digital fiberoptic control technology

#### ABWR-II: Safety System

Safety goals:

- Combination of active and passive systems.
- 1 day grace period for both transients and accidents.
- Combination of severe accidents from design stage.
- PSA performance equal to or higher than ABWR.

ABWR-II design pursues the optimization of safety and economic aspects.

Emergency Core Cooling System (ECCS) is similar with that of the ABWR, but the capability is extended.

- ECCS is divided into four sub-systems.
- Power sources were diversified.
- Advanced Reactor Core Isolation Cooling (ARCIC) system was developed.
- Passive heat removal system was adopted.



## Technology development for water cooled reactors

### ELSA: E-Learning Module on Severe Accidents

#### Module 1

##### Accidents in nuclear installations

- 1.1 Classification of accidents
- 1.2 Historical overview:  
TMI-2, Chernobyl, Fukushima

#### Module 2

##### Early and late in-vessel phases

- 2.1 Reflood phenomena
- 2.2 Zirconium oxidation
- 2.3 Loss of rod-like geometry
- 2.4 Vessel failure modes
- 2.5 Corium release

Quiz

#### Module 3

##### Ex-vessel phase

- 3.1 Fuel-coolant interaction (FCI) and steam explosion
- 3.2 Corium melt spreading
- 3.3 Direct containment heating
- 3.4 Molten core-concrete interaction (MCCI) and basemat behavior
- 3.5 Modes of containment failure

Quiz

#### Module 4

##### Hydrogen and source term

- 4.1 Hydrogen generation
- 4.2 Hydrogen distribution and burn
- 4.3 Physics and chemistry of Source term (ST)
- 4.4 Fission products (FP) behavior and transport

Quiz

#### Module 5

##### Mitigation of accident consequences

- 5.1 In-vessel melt retention
- 5.2 Ex-vessel melt retention
- 5.3 Hydrogen mitigation
- 5.4 Mitigation of FP release
- 5.5 IAEA SAMG-D toolkit

Quiz

#### Module 6

##### Severe accident R&D

- 6.1 Severe accident R&D priorities
- 6.2 Experimental R&D
- 6.3 Severe accident codes

Quiz

Overview QUIZ



## Technology development for water cooled reactors

### Hub for Open-Source Nuclear Power Plant Part-Task Simulators (HOPS)

#### Purpose

Develop a hub for open source nuclear power plant part-task simulators in support of nuclear power programmes development in Member States

#### Outcome

Strengthened national capabilities on hands-on education and training programmes on nuclear power plant operations

#### Activities

- ✓ Collect the nuclear power plant part-task simulators that are open-source based from the developers in Member States and provide detailed description on their applications and use
- ✓ Synchronise the collected nuclear power plant open-source part-task simulators with standardized approach and GUI
- ✓ Systematise an expanded range of training and demonstration activities on nuclear power plant fundamentals (systems and subsystems operational performances and their roles in overall operation of a nuclear power plant) with open-source part-task nuclear power plant simulators
- ✓ Create a forum in which expert's advice and technical guidance may be provided on the Agency's programme in the area

#### Outputs

- ✓ Variety of open-source part-task nuclear power plant simulators on specific plant characteristics of interest to Member States
- ✓ Hands-on learning tools on nuclear power plant systems and subsystems
- ✓ Interactive educational approaches addressing fundamentals of nuclear power plant operation with the use of these open-source part-task nuclear power plant simulators
- ✓ Training course series addressing the specifics of the collected open-source part-task nuclear power plant simulators with examples and exercises
- ✓ A strong community of developers in the field of simulators for nuclear engineering applications



# International HOPS School



Enhancing Human Resource Development with Hands-on Learning-by-Doing Nuclear Power Plant Part-Task Simulators

## NPTDS Proposal to 2022-23 TC Project [PCMF, January 2020]

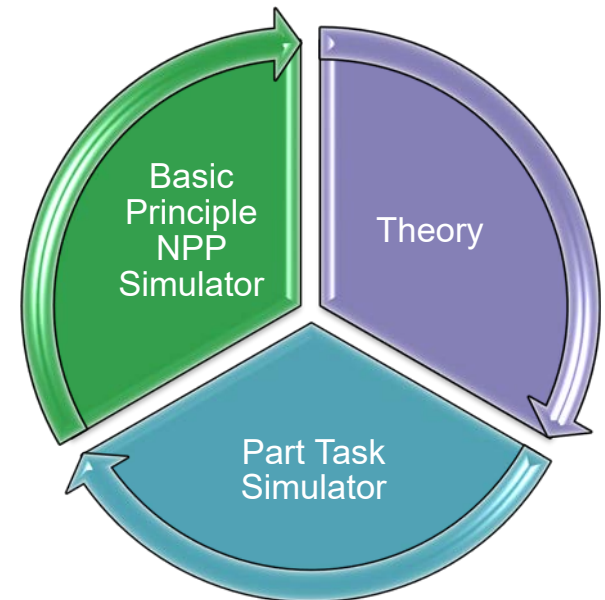
Area: Education and Training, Capacity Building

### Overall Objective:

Supporting Member States with less advanced education and training nuclear power programmes, by making available the relevant skills, knowledge, programmatic training approaches and educational hands-on tools

### Overview

1. Theoretical lectures provided by NPTDS and external experts (developed countries) on different advanced reactor technologies, passive safety systems, severe accidents, ...
2. Using IAEA's PC based basic principle simulators to teach the complete system engineering with hands-on exercises and new TCSs
3. FOAK training and education approach:  
International HOPS School  
Using IAEA's part task simulators (HOPS), to simulate each system/sub-system with hands-on exercises:  
participants to develop their own part-task simulator during the course [ develop new TCSs]



# **SANIS: Simulation and experimental Analyses Network Information System**



- **The SANIS system will contain information on the world's experimental facilities and analytical tools related to operation of water cooled reactors**
  - Addresses phenomena from normal operation to design extension conditions with core melt
  - May include reference data for code development and assessment
  - Provide supporting information and documentation, news, activities and links
- **Within the system, the database will be structured into sections, dedicated to specific phenomena, e.g.**
  - Reactor physics
  - Fuel behavior
  - Thermal hydraulics
  - Hydrogen distribution, deflagration and detonation
  - Codes used for plant analysis
  - Learning tools
- **The information in the system will be periodically updated directly by facility provider or code developer, reviewed and accepted by the IAEA**
- **The system will be used as a collaborative platform to allow infrastructure and facility operators as well as code developers to better identify the resources available to them**

## SANIS

# Simulation and experimental Analyses Network Information System

Technology development for water cooled reactors

### Codes

- Codes for analysis of plants in normal operation and accident conditions
- Reactor physics, fuel behavior, containment analysis
- Reference data for code development and assessment
- Supporting information and documentation, news, activities and links

### Facilities

- Integral and separate-effects test facilities to study conditions from normal operation to design extension conditions with core melt
- Thermal hydraulics
- Containment behavior
- Corium behavior
- Fission products
- Hydrogen distribution, deflagration and detonation
- Accident management

### Learning Tools

- eLearning Modules (**WCR Technology** and link to **SAMG-D**)
- Part task and basic principle simulators
- Links to **ARIS** and **THERPRO** databases



**IAEA**

International Atomic Energy Agency  
*Atoms for Peace and Development*



Technology development for water cooled reactors

# OUTLINE

1. WCR Team Activities
2. Data Bases: ARIS, THERPRO
3. Educational Simulators and eLearning Modules
- 4. Reactor Technology Assessment**
5. Summary and Outlook

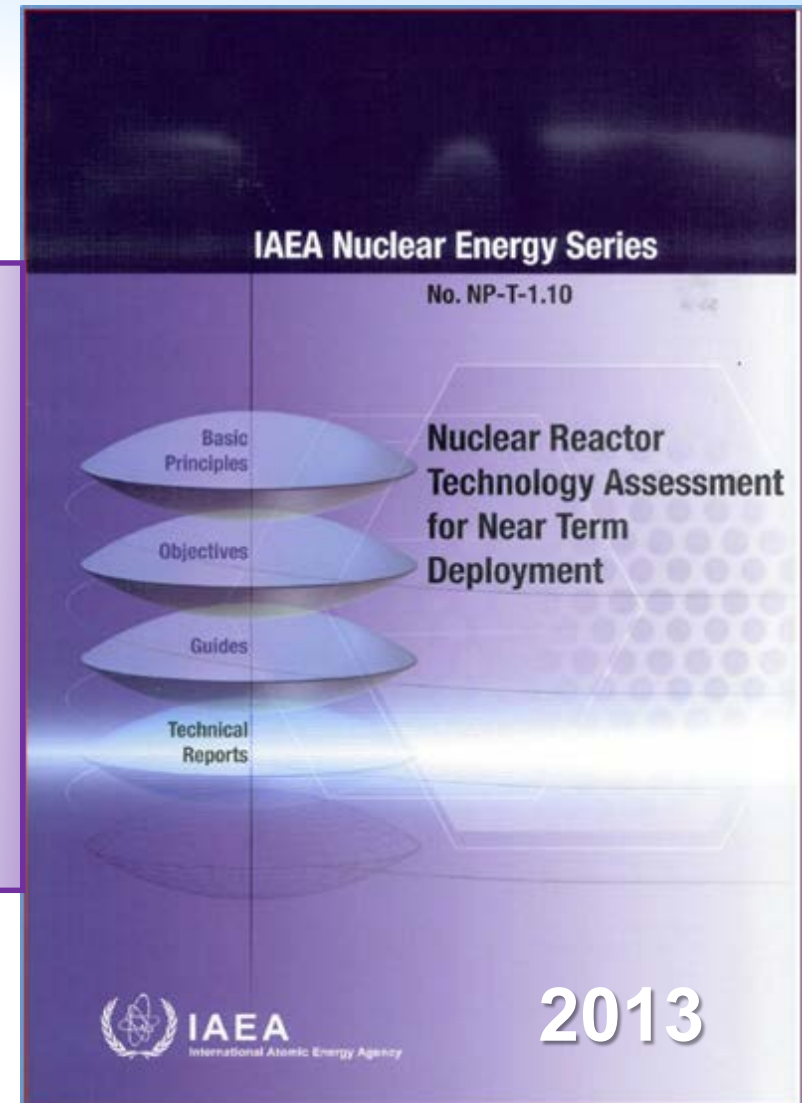
# IAEA RTA Methodology

**OBJECTIVE:** RTA methodology as a **training tool** supporting capacity building in Member States

**PURPOSE:** RTA as a decision making approach providing comprehensive information on complexity of required *facts & figures* for an unbiased assessment of reactor technologies

**RTA Toolkit reflecting the RTA methodology:**

- Applicable to training case studies
- Used in the training courses



# **National RTA (WCRs and **SMRs**) Training Workshops with Exercises, PC Simulators & ARIS Database**



**Preparing the new comer countries in supporting their national human resource development toward reactor technology assessment**

# International RTA (WCRs and SMRs) Training Workshops with Exercises, PC Simulators & ARIS Database



# **New RTA Methodology**

## **– Training Approach–**

---

### **Retasland**

Fictitious country providing framework for the RTA training describing the national goals, site specifics, grid, ...

### **ARIS Database Reactor Descriptions**

As input for RTA training tables

### **RTA Training Tables**

15 Key Elements and Key Topics with justifications

# Retasland

Fictitious country providing framework for the RTA training describing the national goals, site specifics, grid, ...



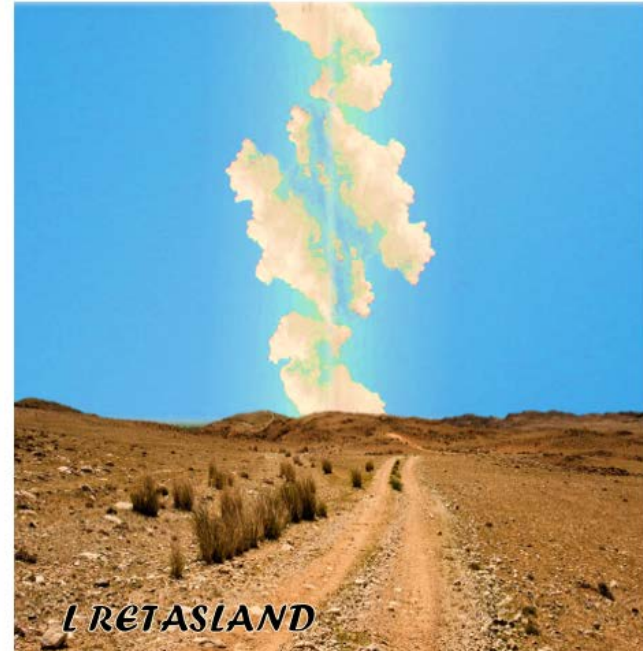
## IAEA METHODOLOGY FOR REACTOR TECHNOLOGY ASSESSMENT (RTA)

### CASE STUDY TRAINING BOOKLET

NUCLEAR POWER TECHNOLOGY DEVELOPMENT SECTION  
DEPARTMENT OF NUCLEAR ENERGY

This document was prepared for **training purposes**. It contains descriptions relevant to the IAEA methodology for RTA.

The country **RETASLAND** does not exist.



## IAEA METHODOLOGY FOR REACTOR TECHNOLOGY ASSESSMENT (RTA)

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Fictitious country providing framework for the RTA training describing the national goals, site specifics, grid, ...



## IAEA METHODOLOGY FOR REACTOR TECHNOLOGY ASSESSMENT (RTA)

### CASE STUDY TRAINING BOOKLET

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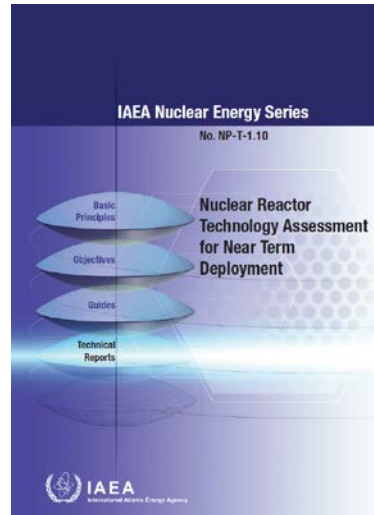
The country **RETASLAND** does not exist.

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# IAEA RTA IT-Toolkit

Under development



Overview

IAEA

TOOLKIT FOR REACTOR TECHNOLOGY ASSESSMENT

Developed by the Nuclear Power Technology Development Section  
Division of Nuclear Power, Department of Nuclear Energy  
INTERNATIONAL ATOMIC ENERGY AGENCY

\* Form completed 2019-05-30

EVALUATOR INFORMATION

Name

Organisation/Country

Go Next

Reactor Selection

Please select the type of reactor

☐ Large Reactor ☒ SMR

Please select the number of reactors to be assessed

☐ 1 ☐ 2 ☒ 3 ☐ 4 ☐ 5 ☐ 6 ☐ 7 ☐ 8 ☐ 9 ☐ 10 ☐ 11 ☐ 12

Reactor#1 SMART (WC-SMR)

Reactor#2 NuScale (WC-SMR)

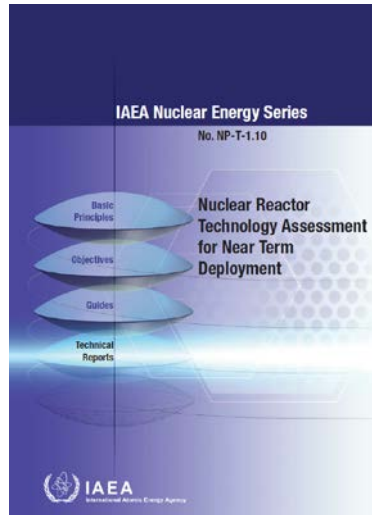
Reactor#3 HTR-PM (GC-SMR)

Go Previous Go Next

Reactor type

Number of reactors to assess

Selected reactor designs



### SITE SPECIFIC CONSIDERATIONS

#### INFORMATION FOR SITE SPECIFIC CONDITIONS

##### Most of the information in this survey was extracted from:

- Nuclear Reactor Technology Assessment for Near Term Deployment, No. NES NP-T-1.10, Section 4.1.1 (pages 29-30)
- [http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1597\\_web.pdf](http://www-pub.iaea.org/MTCD/Publications/PDF/Pub1597_web.pdf)

**Description:** Site specific parameters affecting the plant design.

**Importance factor rational:** Note that the interaction between site characteristics and the features of the proposed design may be strong differentiators (e.g. design features that have been included in the standard nuclear power plant for external events).

##### Site parameters compared with the site parameters envelope offered by the technology holder for the proposed (standard) plant, for example:

- Soil conditions (soft, medium, rock);
- Site seismic level ground acceleration (e.g. safe shutdown earthquake ground motion, operating basis earthquake ground motion);
- Wind velocity;
- Snow load;
- Environmental conditions (barometric pressure, temperature, relative humidity, etc.);
- Cooling water temperatures (for non-safety related cooling systems and safety related cooling systems, and ultimate heat sink considerations);
- Site ambient temperatures and relative humidity for HVAC (heating, ventilation, air conditioning) system design (non-safety and safety related HVAC systems);
- Condenser cooling water source;
- Heat sink temperature (note: this impacts the design of heat exchangers, pumps and the safety analyses. The resultant designs of the heat exchangers and pumps impact the plant electrical output);
- Condenser temperature rise (note: this is determined by the circulating water and service water flows, which in turn affect plant performance);
- Seismic design basis and site differences, including impact on structures and embedment given soil interaction analysis for the site spectra; seismic requirements for the turbine island;
- Water resources required for plant make-up, blowdown and margin required for operation.

##### Key questions:

Question for the owner/operator:

1. What is the range of acceptable plant ratings for this procurement?

Questions for the technology holders:

1. What is the size or weight of your largest component, and how do you propose to transport it to the site?
2. What site specific issues could affect the site preparation schedule and costs?
3. What is the footprint of the major facilities on the site?
4. What is the impact of local temperature variation on plant performance and MW(e) output?

**Evaluation expectations and relative comparisons:** Ensure that each technology holder's plant design and site configuration and characteristics are consistent with the site specific characteristics.

##### Additional references:

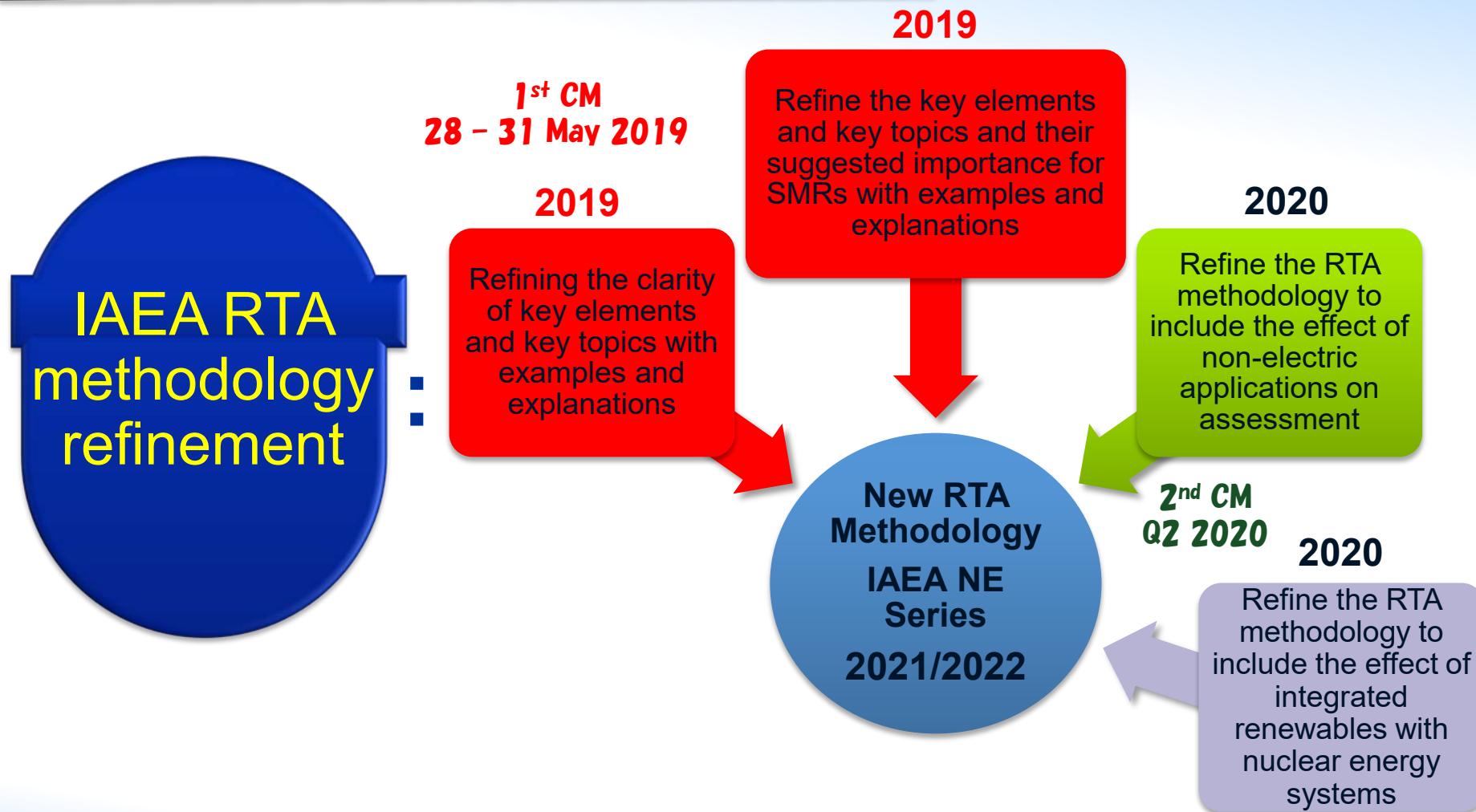
- Site Evaluation for Nuclear Installations No. NS-R-3(Rev. 1); <http://www-pub.iaea.org/MTCD/publications/PDF/Pub1709web-84170892.pdf>
- External Human Induced Events in Site Evaluation for Nuclear Power Plants No. NS-G-3.1; [http://www-pub.iaea.org/MTCD/publications/PDF/Pub1126\\_scr.pdf](http://www-pub.iaea.org/MTCD/publications/PDF/Pub1126_scr.pdf)
- Site Survey and Site Selection for Nuclear Installations No. SSG-35; <http://www-pub.iaea.org/MTCD/publications/PDF/Pub1690Web-41934783.pdf>

| Reactor#1            | Reactor#2            | %                    |                                                                                                              |
|----------------------|----------------------|----------------------|--------------------------------------------------------------------------------------------------------------|
| <input type="text"/> | <input type="text"/> | <input type="text"/> | Summary                                                                                                      |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | Ambient site environmental conditions and ecology, including seismic, flooding, wetlands, population density |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | Heat sink temperature, condenser cooling water source and extent of water resources                          |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | Predicted magnitude and frequency of all external events (design and safety considerations)                  |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | Site size requirements, boundary conditions, population, neighbours and environs                             |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | Transportation routes/facilities and access to required infrastructure for construction and operation        |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | Site development and preparation requirements                                                                |
| <input type="text"/> | <input type="text"/> | <input type="text"/> | Site structure plan, single- or multi-unit site requirements                                                 |

Comments (Optional)

## BOOKLETS on Training Case Studies to publish in 2019

- *S/M* Retasland and SMR technologies
- *L* Retasland and AWCN technologies



Refinement of the RTA methodology through Consultancy Meetings including feedbacks from national and interregional RTA training workshops and experts



**IAEA**

International Atomic Energy Agency  
*Atoms for Peace and Development*



**Technology development for water cooled reactors**

# OUTLINE

1. WCR Team Activities
2. Data Bases: ARIS, THERPRO
3. Educational Simulators and eLearning Modules
4. Reactor Technology Assessment
- 5. Summary and Outlook**

# Summary / Outlook

## WCR Team Activities of Interest to SMRs:

- ❖ ARIS Database
- ❖ THERPRO Database
  
- ❖ Training and Education:
  - Basic Principle Simulators
  - Training Courses
  - Training Course Series: Booklets and Exercises
  
- ❖ Reactor Technology Assessment:
  - Training Courses
  - Training Course Materials for SMRs