International Atomic Energy Agency

Small and Medium Sized Reactors: Development Status and Deployment Potential/ IAEA Activities in support of SMR Development and Deployment

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Definitions/ Developments in Member States

Small Reactor: < 300 MW(e)
Medium Sized Reactor: 300 – 700 MW(e)

- **In the first half of 2008, of the 439 operating NPPs, 134 were with small and medium sized reactors (SMRs)**

- **Of the 36 newly constructed NPPs, 10 were with SMRs**

- **In 2008, not less than 45 concepts and designs of innovative SMRs are being analyzed or developed in** *Argentina, Brazil, China, Croatia, India, Indonesia, Italy, Japan, the Republic of Korea, Lithuania, Morocco, Russian Federation, South Africa, Turkey, USA, and Vietnam*

Incentives for SMRs (1)

Today, the progress of SMRs is largely defined by their capability to address the needs of those users that for whatever reason cannot benefit from large NPP deployments

- ***Countries with small or medium electricity grids < 7000 - 10000 MW(e) peak load***

- ***Settlements and energy intensive industrial sites in remote off-grid locations (permanent frost, islands, remote draught areas, etc.)***

- ***Countries with limited investment capability (attractive investment profile through incremental capacity increase)***

Incentives for SMRs (2)

➢***In the future*, utilities (worldwide) and, possibly, merchant plants for non-electric energy services (look at aircraft, car and other mature industries)**

Primary energy (in developed countries) is utilized in three roughly equal fractions [*]:

- ✓***A third is used to generate electricity;***
- ✓***A third is used in the transportation sector;***
- ✓***A third is used for domestic and industrial heating.***

[*] World Energy Book 2005, World Energy Council: http://www.worldenergybook.com/

SMRs – Recently Deployed/ Under Construction

- ***PHWR/ 692 MW(e) (Siemens design 1980s) – Under construction in Argentina (Atucha-2, Buenos Aires, 2010/10/01)***
- ***CANDU-6/ 650 MW(e) (AECL, Canada) – Chernavoda, Romania, 2008/08/07***
- ***CNP-600/ 610 MW(e) (PWR, China) – Two units under construction (Quinshan 2-3 and 2-4, 2010/12/28 and 2011/09/28)***
- ***PWR/ 300 MW(e) (China) – Under construction (Punjab, Pakistan, 2011/05/31)***
- ***PHWR-220/ 202 MW(e) (NPCIL, India) – Two units commenced in 2007-2008 (KAIGA-4, 2008/07/31 and RAJASTHAN-5, 2008/06/30), one unit under construction (RAJASTHAN-6, 2008/12/01)***
- ***PFBR-500/ 470 MW(e) (IGCAR, India) – Under construction in India (TAMIL NADU)***
- ***Floating NPP with two KLT-40S reactors/ 2x35 MW(e) (Rosenergoatom, Russia) – under construction in St. Petersburg (Russia) - 2010***

SMRs - Options for Immediate Deployment

Few options are available:

- ***CANDU-6/ EC-6 (AECL, Canada)***

- ***PHWR-220; PHWR-540 (NPCIL, India), attractive capital cost of 1700 – 1800 US$/kW(e)***

- ***PWRs: ~300 MW(e) (China) – built in Pakistan;***
  CNP-600 (China) – built in China

SMRs - Options for Near-Term Deployment

Reactors with Conventional Refuelling Schemes

PWRs with integrated design of primary circuit

- **IRIS - Westinghouse (USA) + Intl. Team**
- **SMART – KAERI, the Republic of Korea**
- **CAREM – CNEA, Argentina**

PWRs – marine reactor derivatives

- **KLT-40S – Rosenergoatom, Russia**
- **VBER-300 – OKBM + Government of Kazakhstan, Rosatom**

Advanced Light Water Cooled Boiling Water Moderated Reactors, Pressure Tube Vertical Type

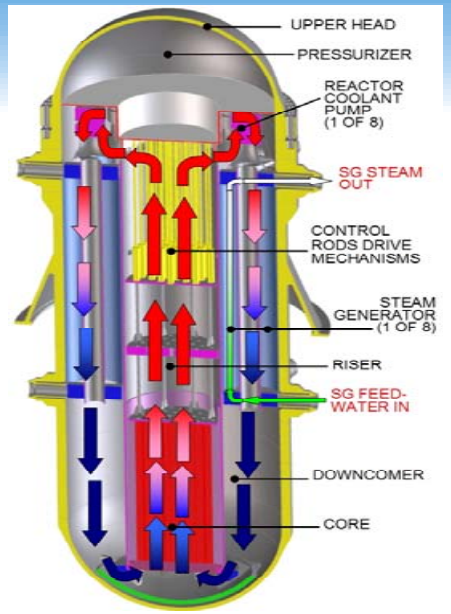
- **AHWR – BARC, India**

High Temperature Gas Cooled Reactors

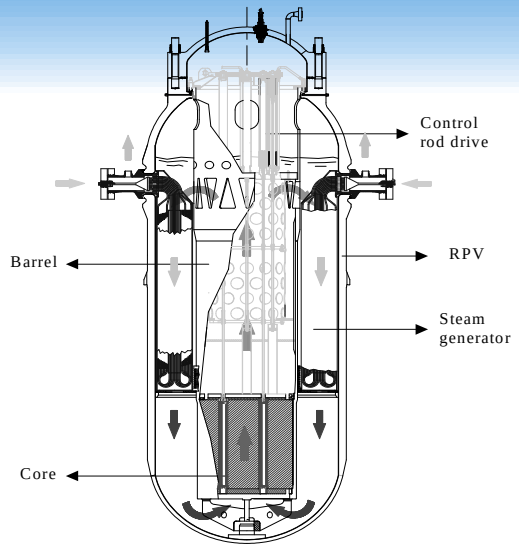
- **HTR-PM – INET, China**
- **PBMR – PBMR Pty, Ltd., South Africa**

Small Reactors without On-site Refuelling

- **ABV – OKBM, Russia; MASLWR – NuScale (USA)**



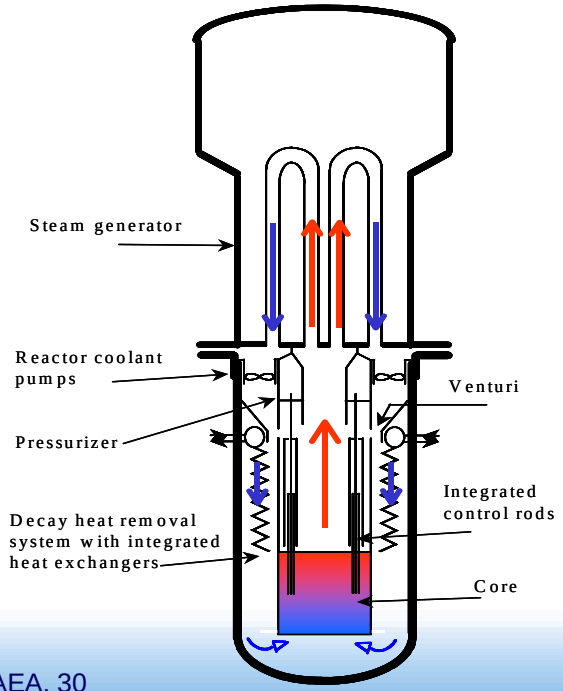
(a)



(b)

Reactor Types/ Distinct Groups (Examples)

Pressurized Water Reactors/ Integral Design PWRs



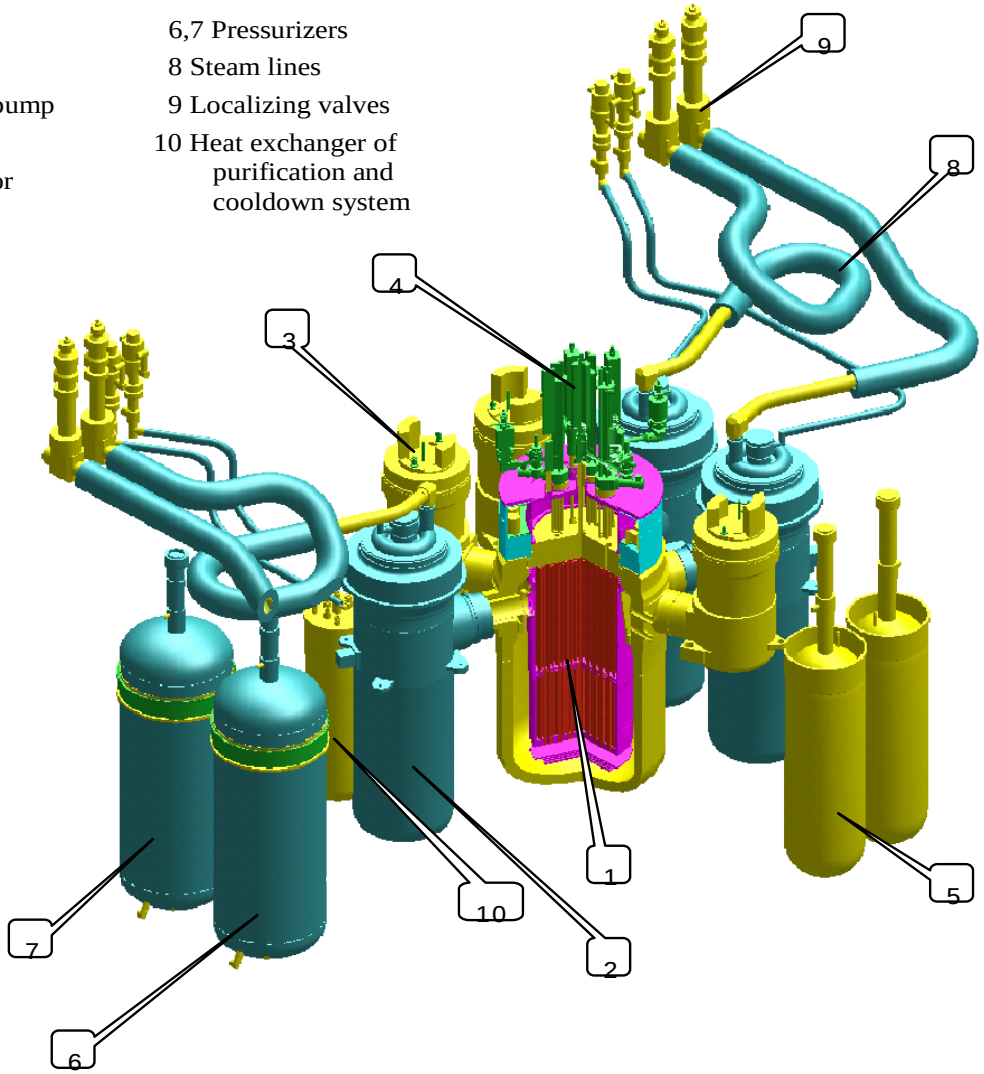
(c)

(a) IRIS – Westinghouse, USA
(b) CAREM – CNEA, Argentina
(c) SCOR – CEA, France

Reactor Types/ Distinct Groups (Examples)

Pressurized Water Reactors/ Marine Reactor Derivatives

1 Reactor
2 Steam generator
3 Main circulating pump
4 CPS drives
5 ECCS accumulator
6,7 Pressurizers
8 Steam lines
9 Localizing valves
10 Heat exchanger of purification and cooldown system



Modular layout of the KLT-40S reactor plant (OKBM, Russian Federation).

Reactor Types/ Distinct Groups (Examples)

High Temperature Gas Cooled Reactors/ Direct gas turbine Brayton cycle

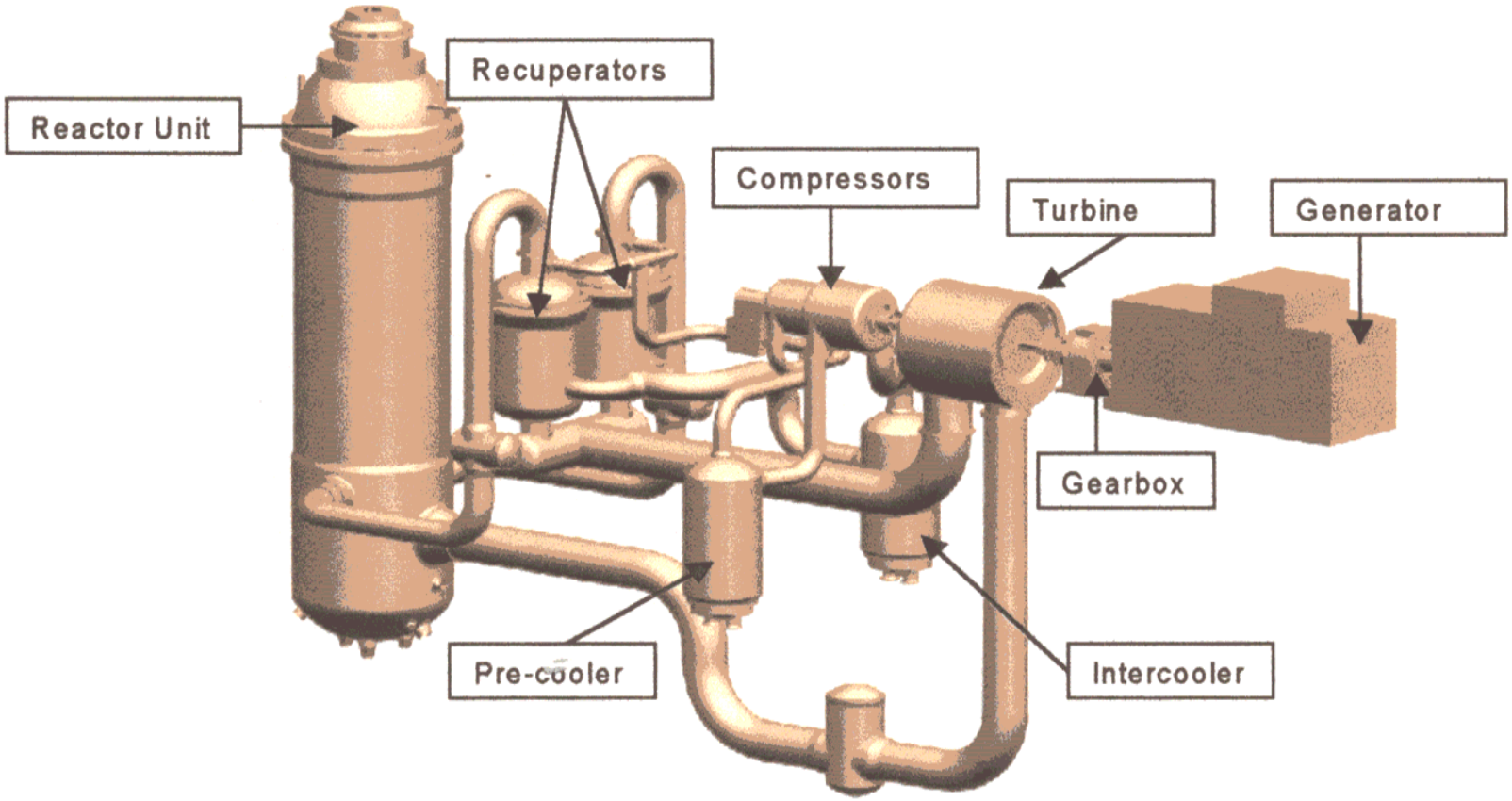


FIG. XIV-2. Conceptual layout of the PBMR primary system [XIV-3].

Common Features of SMRs

- ***A variety of flexible and effective non-electrical application options (i.e., co-generation)***

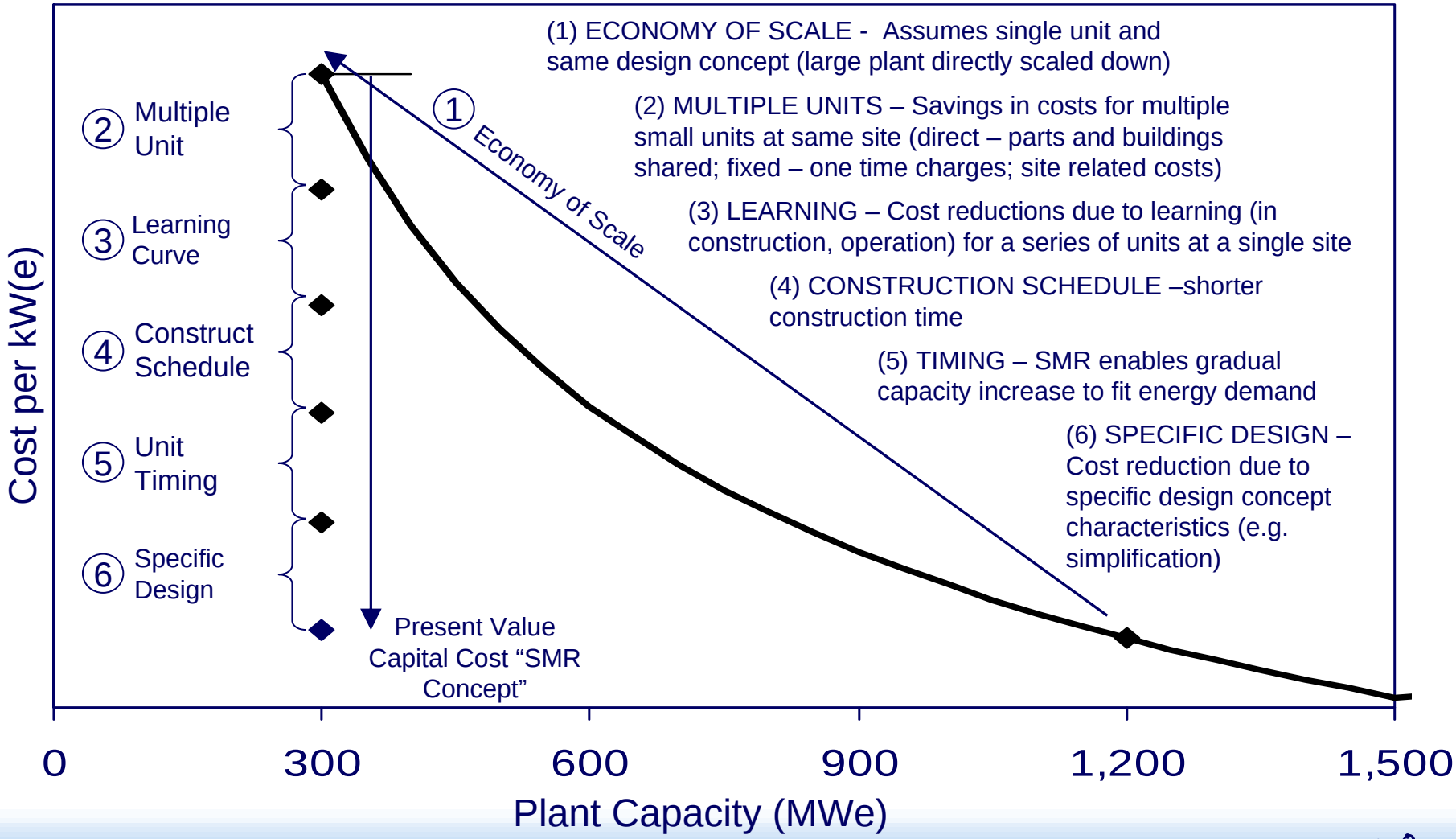
- ***Potentially, smaller emergency planning zone and proximity to the users***

- ***Flexible and just-in-time capacity addition***

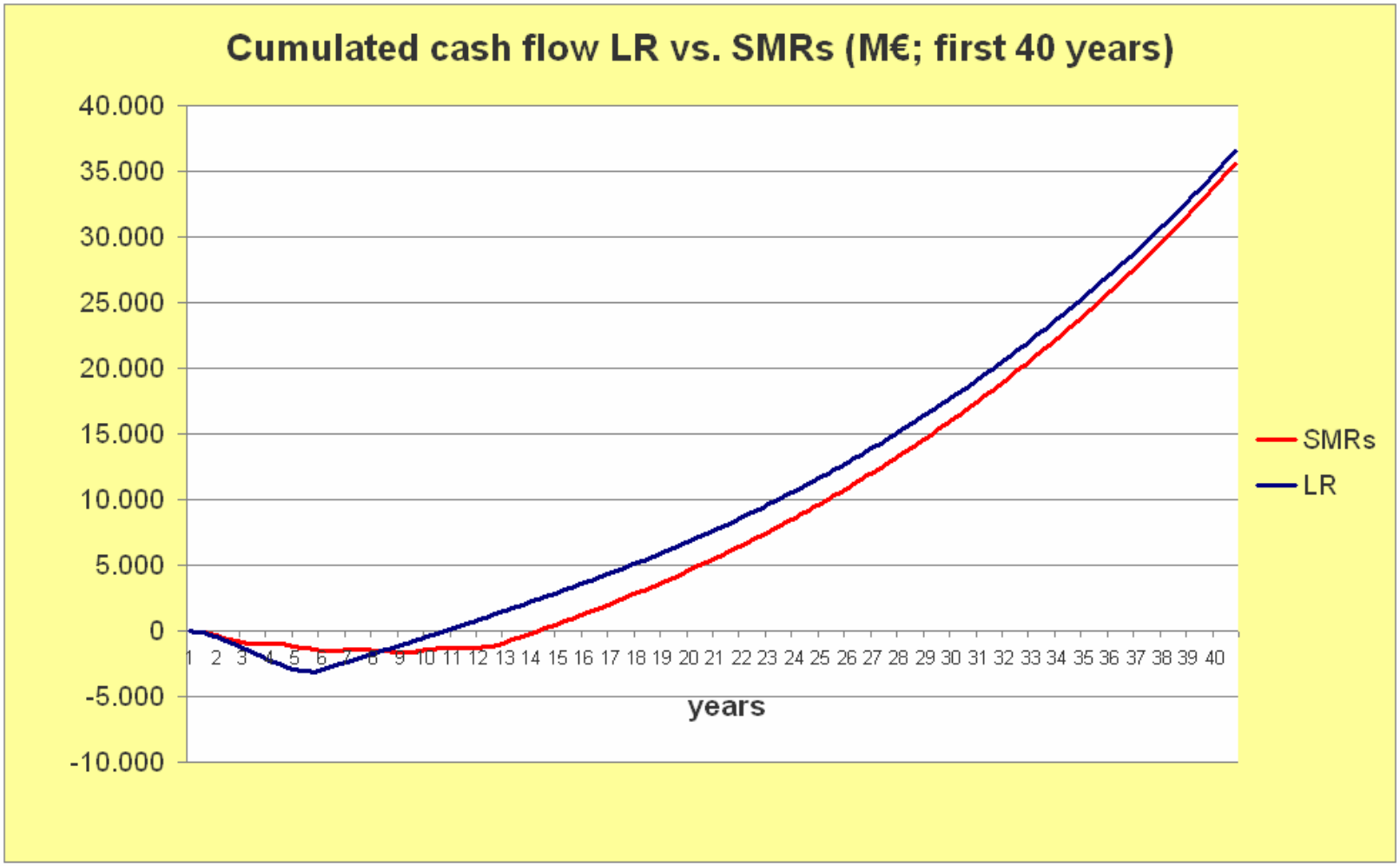
- ***For small reactors without on-site refuelling: long refuelling interval and all operations with fuel outsourced***

How to Combat Economy of Scale?

Present Value Capital Cost (PVCC) Model – Westinghouse, USA



Incremental Capacity Increase May Be of Benefit For Countries with Limited Investment Capability



Project "Common Technologies and Issues for SMRs"

Participants:

Argentina, Brazil, China, Croatia, European Commission, NEA-OECD, France, India, Indonesia, Italy, Japan, the Republic of Korea, Lithuania, Morocco, Russian Federation, Turkey, South Africa, USA, Vietnam

Deliverables 2005-2007:

- ✓ **TECDOC-1451 (May 2005) "Innovative SMRs: Design Features, Safety Approaches, and R&D Trends"**
- ✓ **TECDOC-1487 (Feb. 2006) "Advanced Nuclear Plant Design Options to Cope with External Events"**

Status Reports:

- ✓ **TECDOC-1485 (Mar. 2006) "Status of Innovative SMR Designs 2005: Reactors with Conventional Refuelling Schemes"**
- ✓ **TECDOC-1536 (Jan. 2007) "Status of Small Reactor Designs without On-Site Refuelling"**

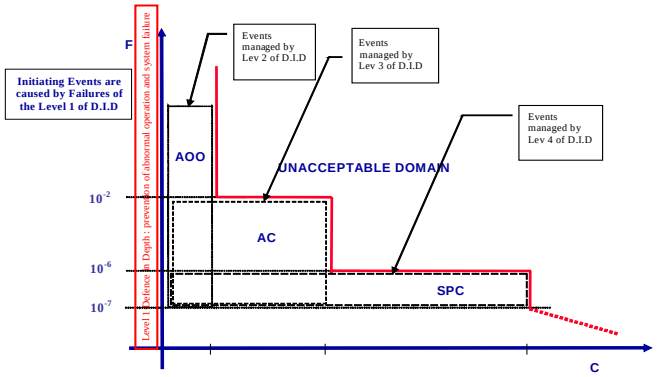
Ongoing activities - Examples

Nuclear Energy Series Report "Design Features to Achieve Defence in Depth in SMRs"

Status: Publication endorsed by the Document Coordination Team of the NE; clearance process ongoing

10 representative SMR concepts presented in line with the recommendations of the IAEA Safety Standards, with a focus on Defence in Depth Strategy

KLT-40S, IRIS, CAREM-25, SCOR, MARS, AHWR, GT-MHR, 4S-LMR, SSTAR & STAR-LM, CHTR



AOO – abnormal operation occurrences
F – frequency
C – consequences
AC – accidental conditions
SPC – severe plant conditions

FIG. 2. Quantitative Safety Goal and Correlation of Levels of Defence (FIG. 5 from reference [13]).

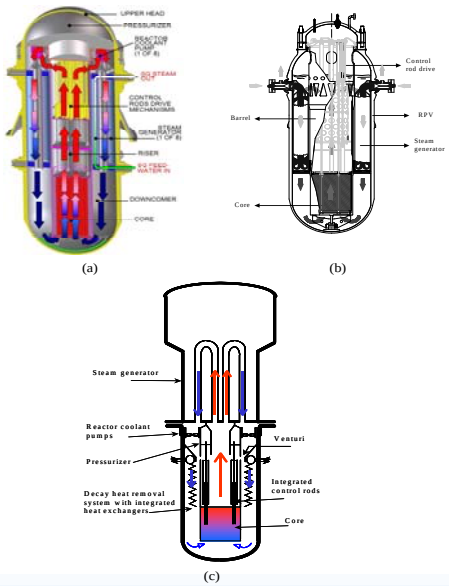


FIG. 4. Schematics of the primary coolant system for (a) IRIS; (b) CAREM-25; and (c) SCOR.

Ongoing Activities - Examples

Nuclear Energy Series Report "Approaches to Assess Competitiveness of SMRs"

Status: Draft in preparation; editing in progress

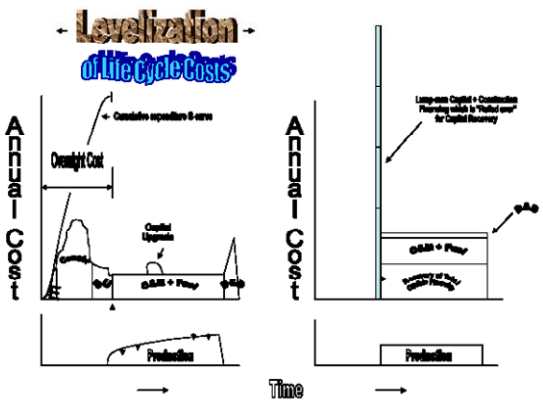
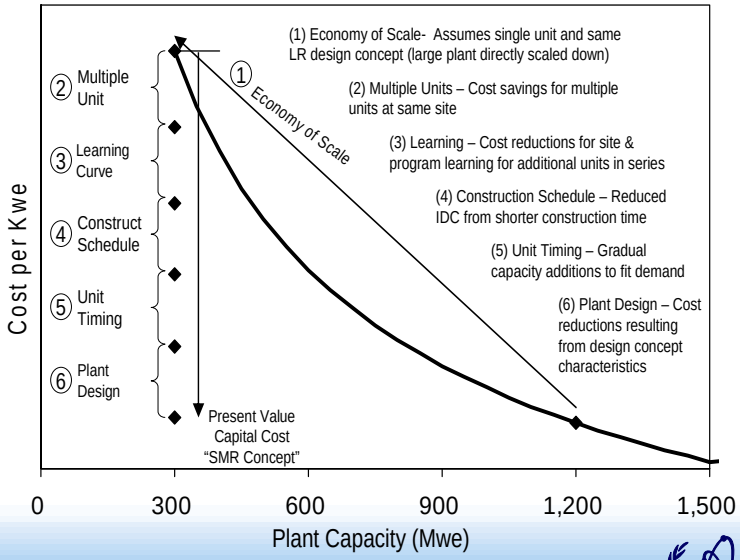


Figure 1. Concept of cost levelization.

- **Suite of methodologies:**
  - ✓ ***Present Value Capital Cost***
  - ✓ ***G4-ECONS***
  - ✓ ***Design simplification assessment***
  - ✓ ***Impact of Uncertainties***
  - ✓ ***MFA models***
  - ✓ ***Consolidated Approach: Open Model***
  - ✓ ***IAEA methodologies***

Figure 2 - Potential SMR Cost Factor Advantages



Ongoing activities - Examples

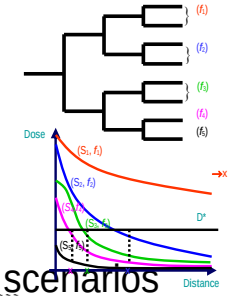
CRP "Small Reactors without On-site Refuelling" (2004 – 2008)

***Group 1:* "Revising the Need for Relocation and Evacuation Measures Unique to NPPs with Innovative SMRs"**

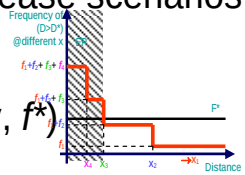
- ***FER University of Zagreb (Croatia) – deterministic analysis of accident sequences***
- ***POLIMI (Italy) – overall model based on risk-informed approach***
- ***LEI (Lithuania) – Non-electric applications and energy supply security***
- ***Westinghouse (USA) – regulatory aspects, etc.***

EPZ Redefinition Methodology

- Step1
  PRA accident sequences re-categorization
  and release scenario definition



- Step2
  Deterministic dose vs distance evaluation for relevant release scenarios
- Step3 (Limiting dose, D*)
- Step4 (Limiting frequency, f*)



- Step5 (EPZ definition)

Activities – Examples – Cooperation with INPRO

"Legal and Institutional Issues of Non-stationary NPPs"

The objective of this activity:

- **Study challenges for deployment of transportable SMRs with a focus on legal and institutional aspects but considering their economics and technical aspects and various deployment options related to ownership and contract**

- **Propose solutions and associated action plans to address the identified challenges**

THANK YOU!

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SMR Projections From Recent Activities of IAEA's Planning and Economic Studies Section

Summary:

- **22 countries in High Case and 10 countries in Low Case**
- **Installed Net Capacities (GWe) and number of the units**

Case	by 2010	By 2020	by 2030	Units
High	3.6	21.2	38.0	96
Low	2.8	13.2	16.8	43

Small or Medium Sized Reactor Does not Mean a Low Capacity Nuclear Power Station

- Several SMRs can be built at a single site
- The majority of SMRs provide for power station configurations with 2, 4, or more NPPs or reactor modules .

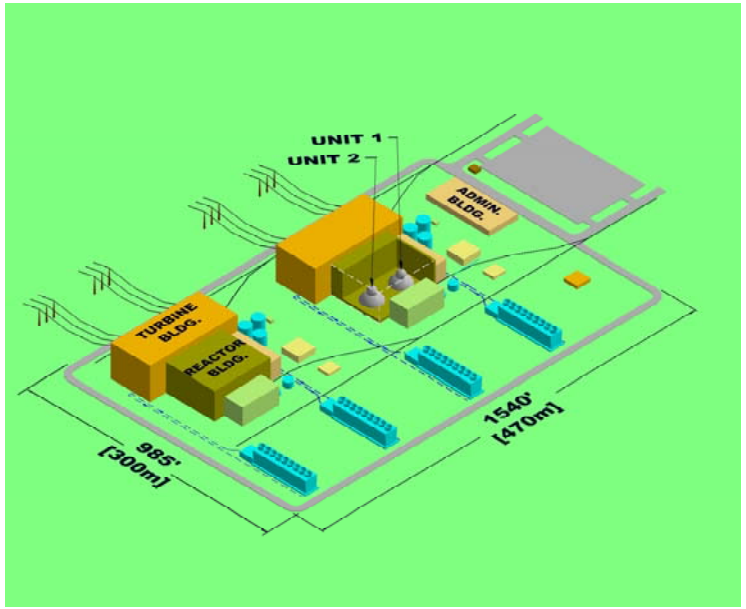


FIG. II-10. Perspective view of IRIS multiple twin-unit site layout.

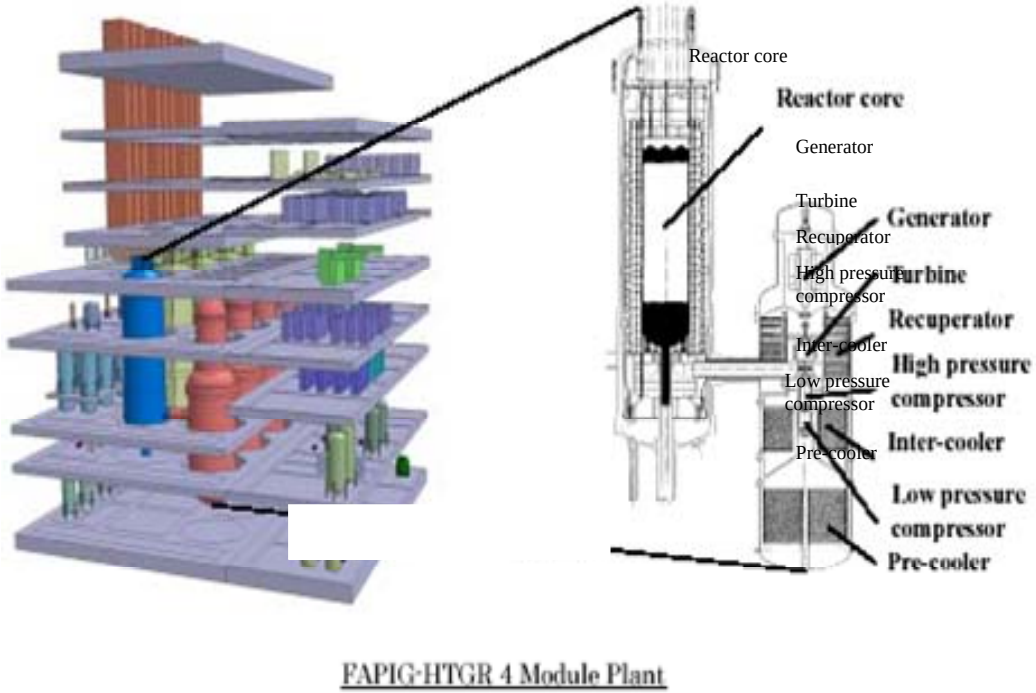
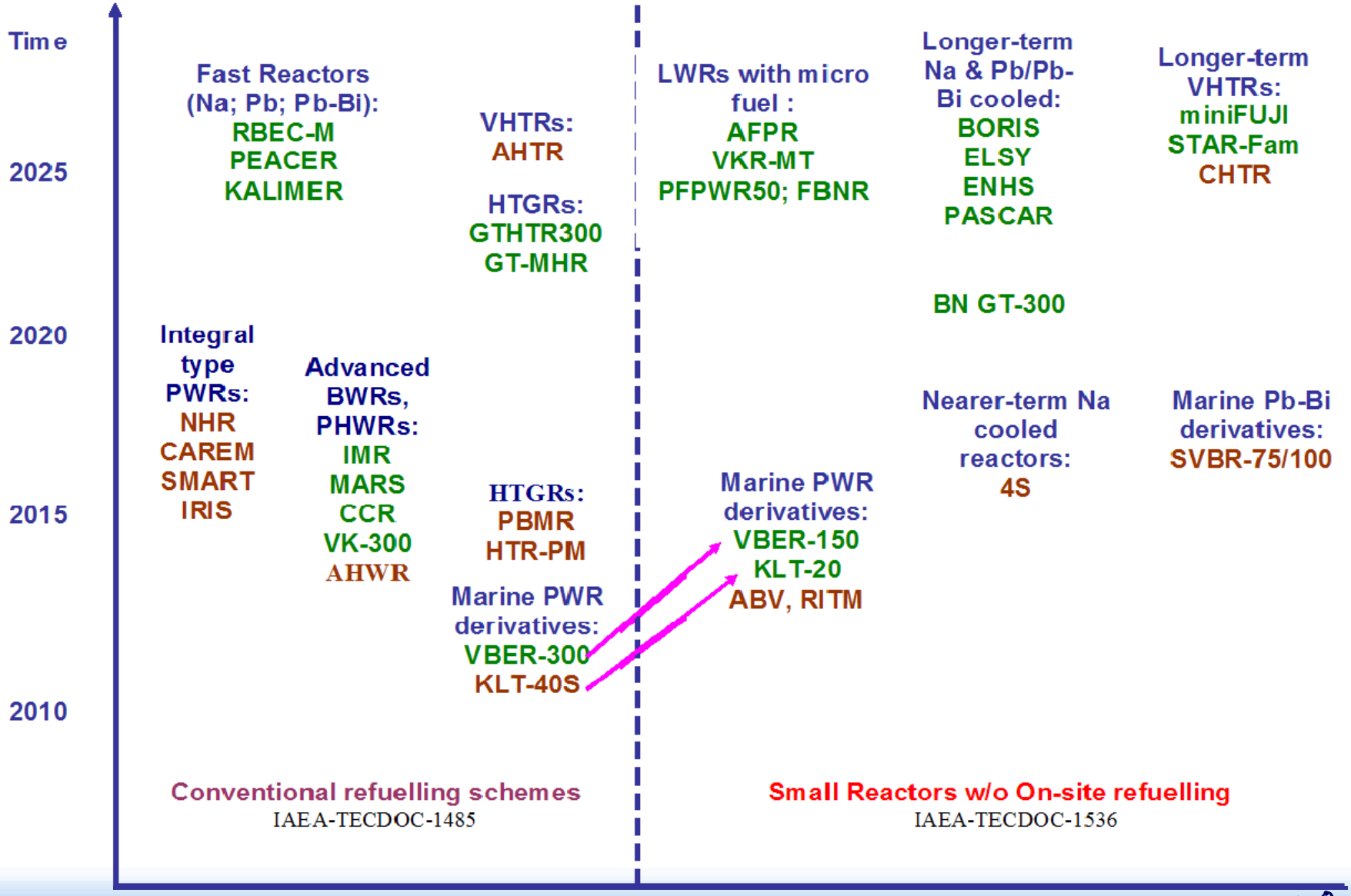


Fig. XVIII-1. Schematic view of the FAPIG-HTGR 4-module plant.

Deployment potential of innovative SMRs



Activities - Examples

Coordinated Research Project "Development of Methodologies for the Assessment of Passive Safety System Performance in Advanced Reactors" (2008-2011)

First Research Coordination Meeting in March 2009.

The objective is to determine a common analysis-and-test method for reliability assessment of passive safety system performance.

Such a method would facilitate application of risk-informed approaches in design optimization and safety qualification of the future advanced reactors, contributing to their enhanced safety levels and improved economics.

Project "Common Technologies and Issues for SMRs"

P&B 2008-2009: 1.1.5.4 Recurrent Project, Ranking 1

Objective:

- To facilitate the development of key enabling technologies and the resolution of enabling infrastructure issues common to future SMRs of various types

Expected outcome:

- Increased international cooperation for the development of key enabling technologies and the resolution of enabling infrastructure issues common to future SMRs of various types