International Atomic Energy Agency

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IAEA Programmes on Small and Medium-sized Reactors

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Outline

- Roles of IAEA on SMRs
- IAEA Programmes on SMR in 2011
- IAEA Programmes on SMR for 2012 – 2013
- Developing Countries Expectations
- Status of SMR designs
- Advantages and Challenges of SMRs
- Options of SMRs for Near Term Deployment
- IAEA's Projects on SMRs
- IAEA's Coordinated Research Project (CRP)
- Summary

Roles of IAEA on SMRs

- Coordinates efforts of Member States to facilitate the development of SMRs by taking a systematic approach to identify key enabling technologies to achieve competitiveness and reliable performance of SMRs, and by addressing common issues to facilitate deployment
- Establishes and maintains international network with international organizations involved on SMRs activities
- Ensures overall coordination of Member States experts by planning and implementing training and by facilitating the sharing of information/experience, transfer of knowledge
- Develops international recommendations and guidance on SMRs focusing to address specific needs of developing countries

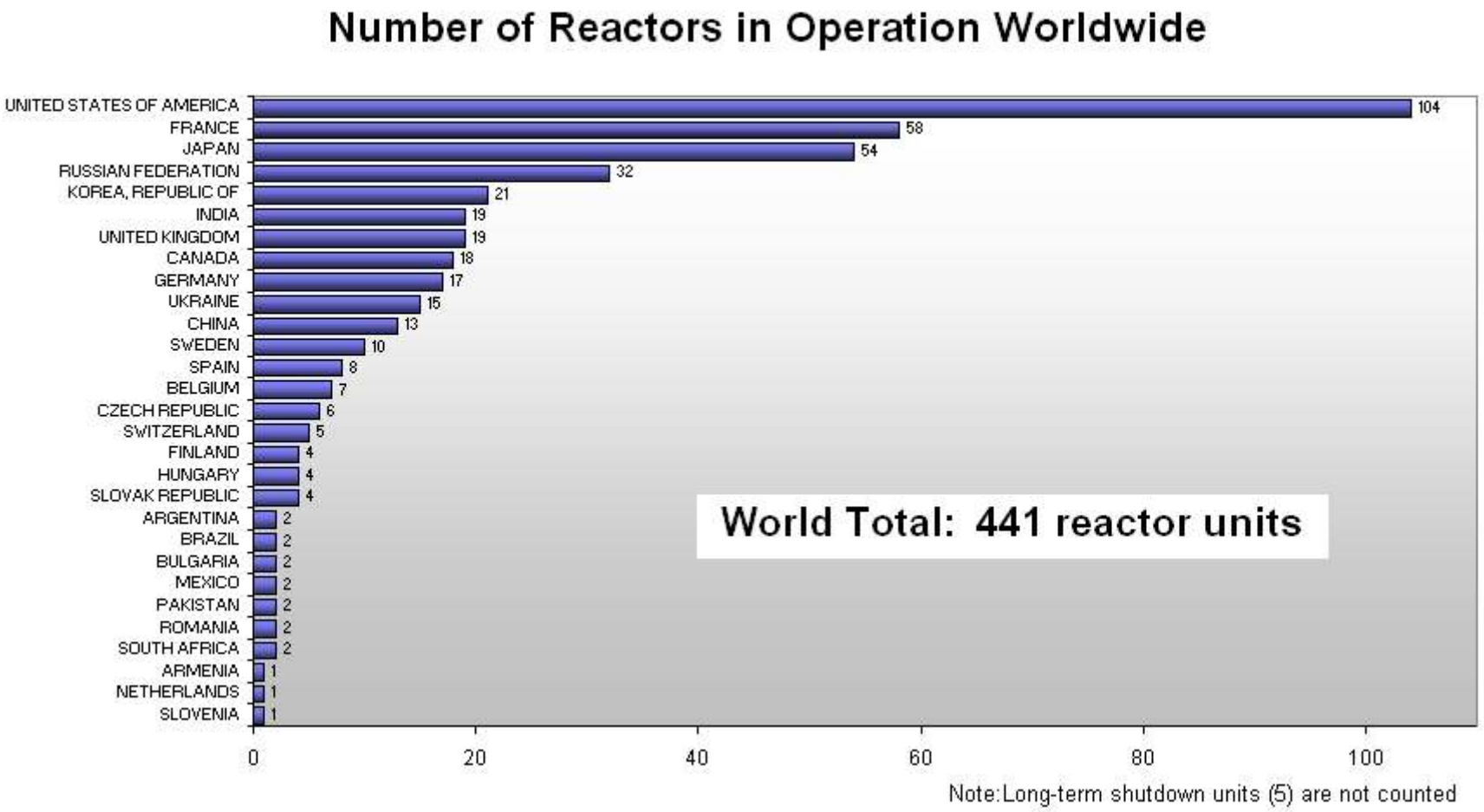
IAEA Programmes on SMRs in 2011

- Consultancy Meeting on "Status of Innovative SMR Designs with a Potential of Being Deployed by 2020"
  - Planned date/place: February 2011 in IAEA - Vienna
- Research Coordination Meeting for the CRP on “Development of Advanced Methodologies for the Assessment of Passive Safety System Performance in Advanced Reactors (I31018)”
  - Planned date/place: 4 -7 April 2011 in IAEA – Vienna
- The 3rd Technical Meeting on “Options to Incorporate Intrinsic Proliferation & Physical Protection to NPPs with Innovative SMRs”
  - Date/place (confirmed): 6 - 9 June 2011 in IAEA – Vienna
- Workshop on Advanced Nuclear Reactor Technology for Near Term Deployment
  - Date/place (confirmed): 4-8 July 2011 in IAEA – Vienna
- CM on "Options to Enhance Energy Supply Security with NPPs based on SMRs“
  - Planned dates and place: 3 -6 October 2011 in IAEA – Vienna
- Workshop on “Technology Assessment of SMR deployable by 2020”
  - Planned and date/place: 1 – 4 November 2011 in IAEA - Vienna

IAEA Programmes on SMR for 2012 - 2013

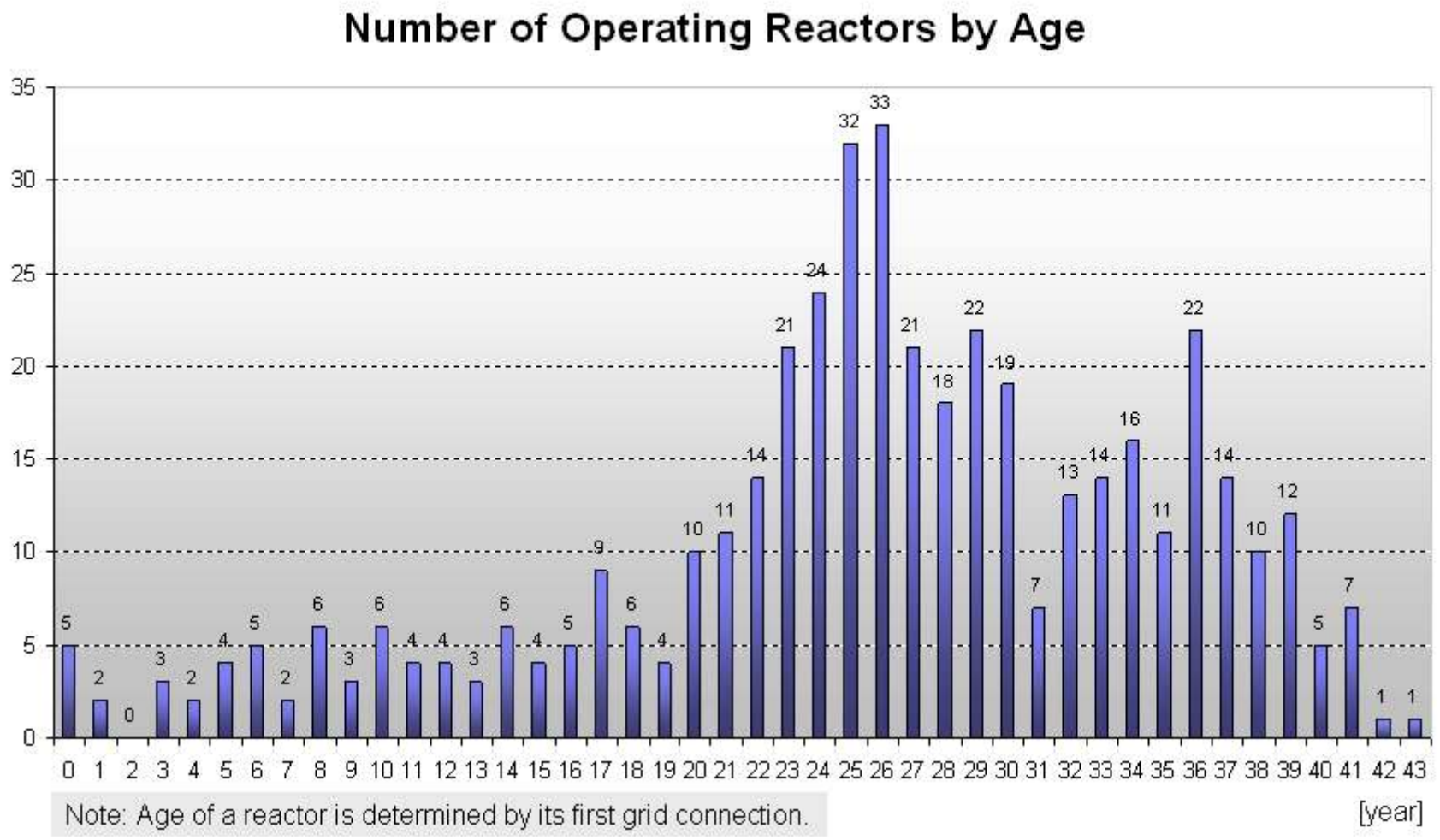
- Develop roadmap for technology development, assessment and deployment - including countries requirements, regulatory and business issues
- Define operability-performance, maintainability and constructability indicators to assist countries in assessing advanced SMR technologies
- Develop Guidance and Tool to Facilitate Countries with Planning for SMRs Technology Implementation
- Application of CFD Codes for the Design of Advanced Water Cooled Reactors - to prepare for an NE series report on Development Status and Prospects for Advanced Computation Methodologies
- Coordinate a CRP on development of methodologies for the assessment of passive safety system performance in advanced
- Provide education and training on various aspects of SMR technology development and assessment and SMR applications
- Develop economic competitiveness evaluation methodology for SMR

Reactors Currently in Operation



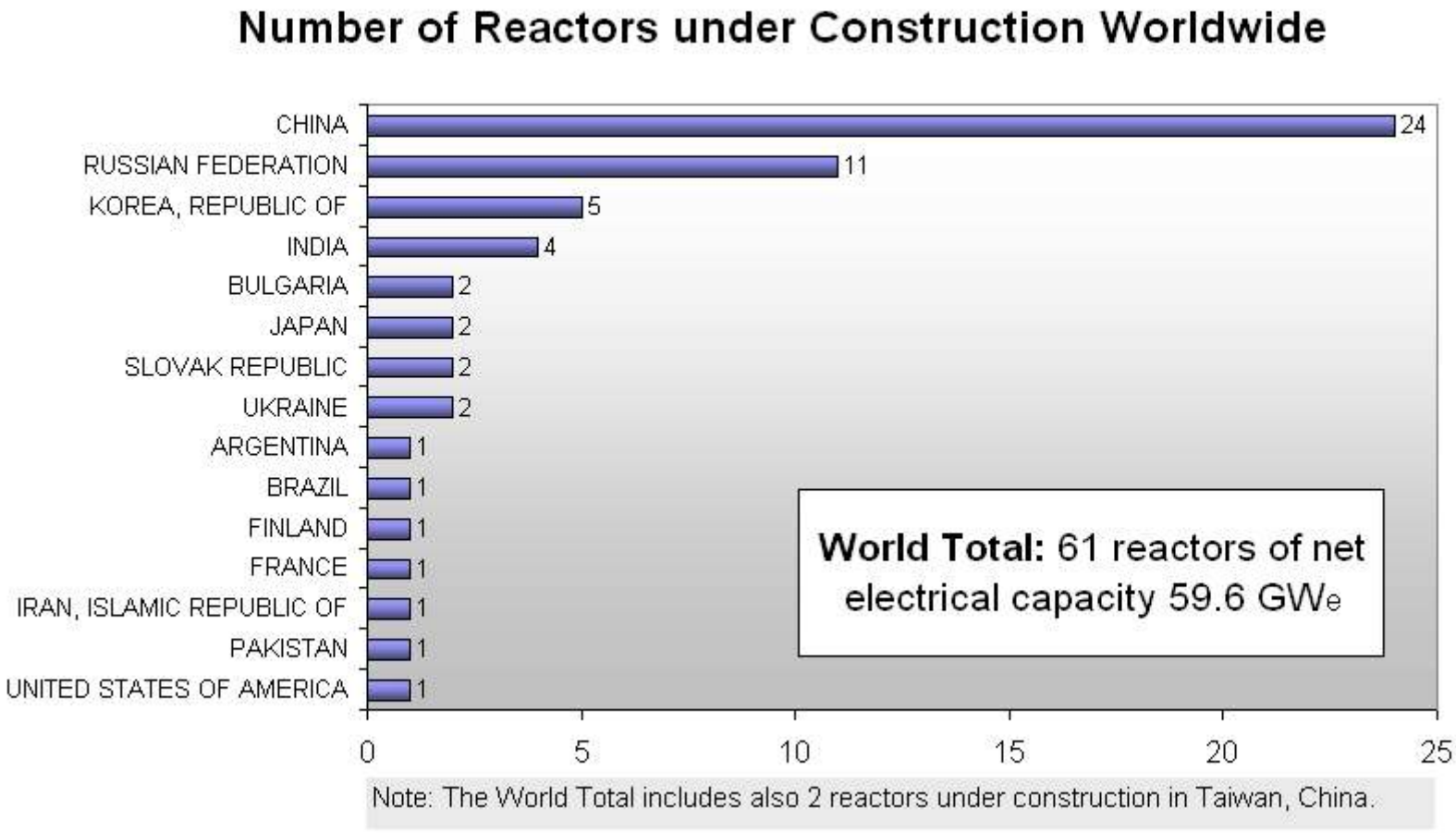
Source: PRIS, IAEA, 11/02/2010

NPPs in Operation by Age



Source: PRIS, IAEA, 11/02/2010

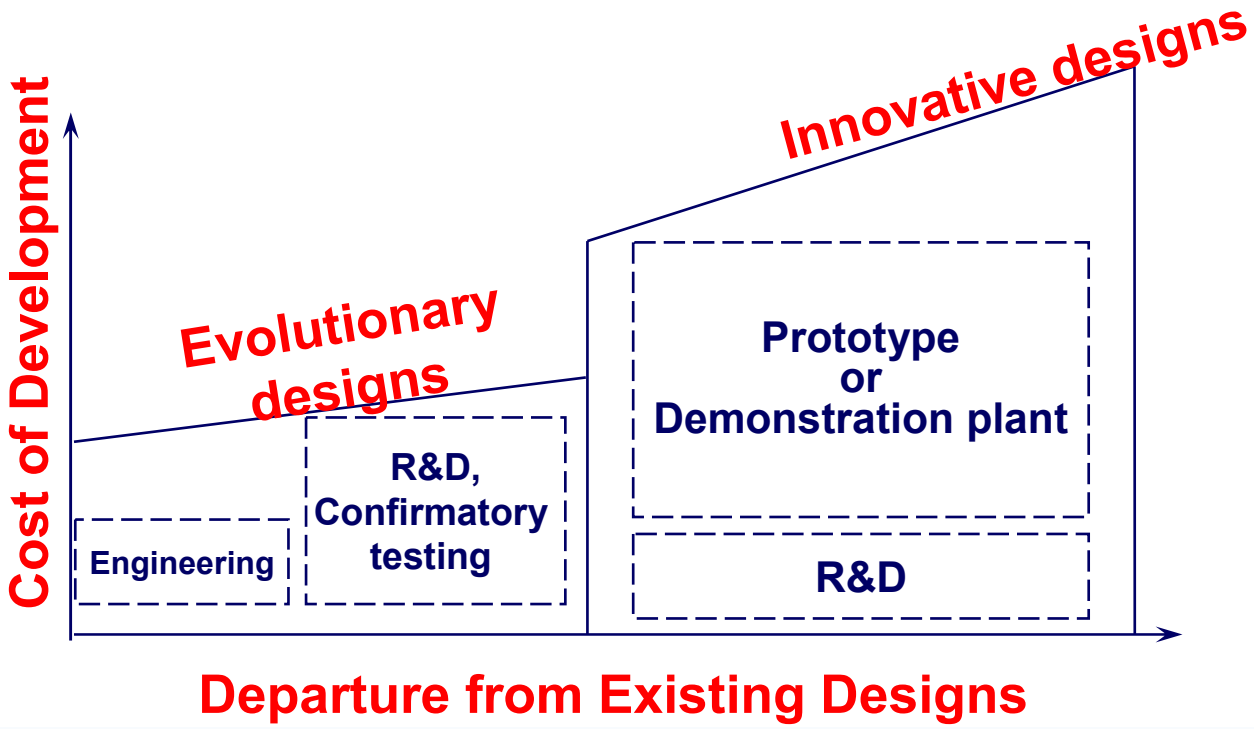
NPPs under Construction



Source: PRIS, IAEA, 11/02/2010

Advanced Reactor Designs

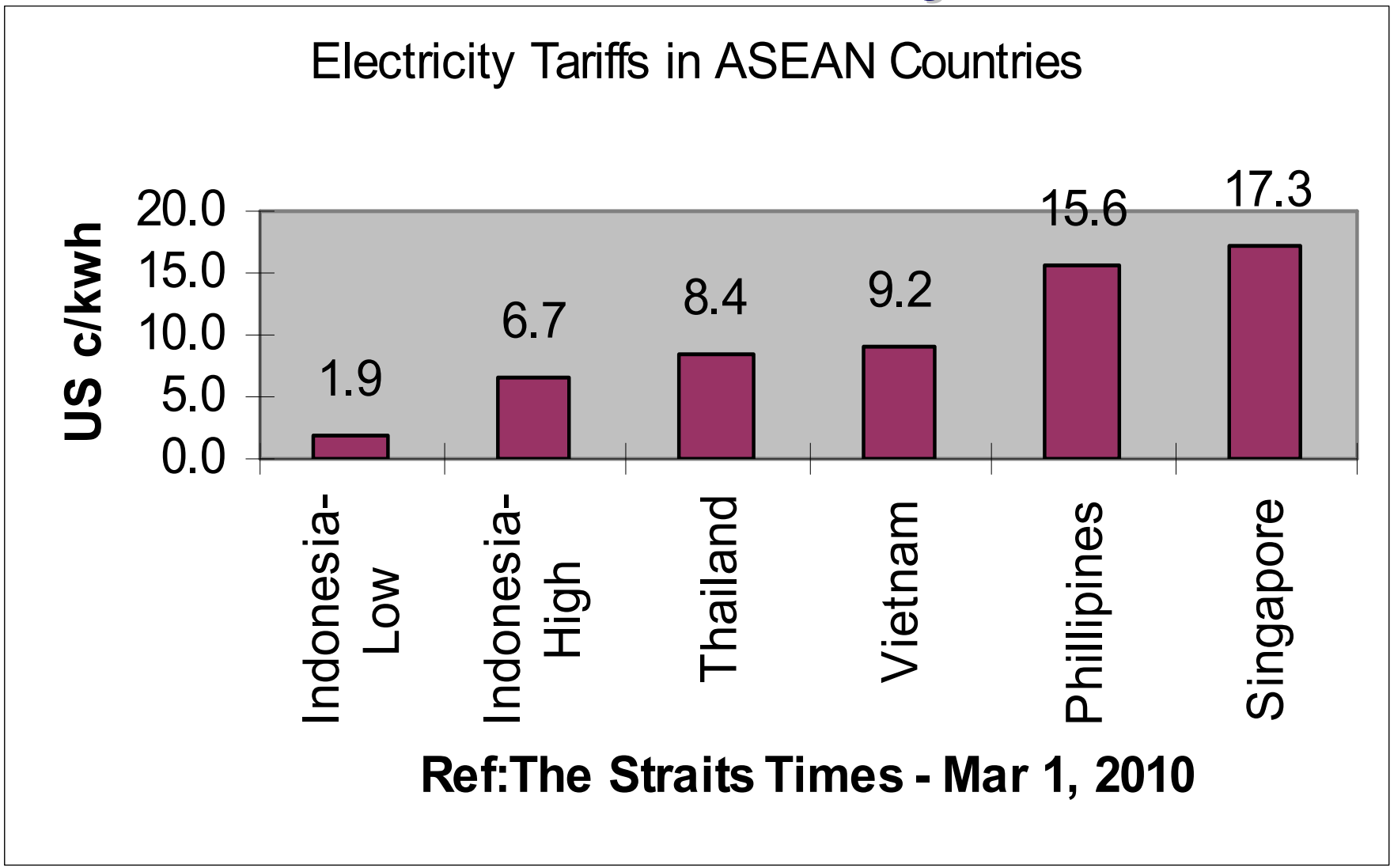
- **Evolutionary Designs - achieve improvements over existing designs through small to moderate modifications**
- **Innovative Designs - incorporate conceptual changes and may require a prototype plant before commercialization**



Developing Countries Expectations

- Developing countries need a lot and spend a bigger fraction on energy
- To improve quality of life by increasing electricity/capita – while investment capability is limited
- Comprehensive study on user requirements
- Proven technology
- Licensing requirements
- Economic competitiveness
- Plant performance
- Assurance of supply
- Proliferation resistance and safety
- Every other year the IAEA General Conference issues Resolution on SMR

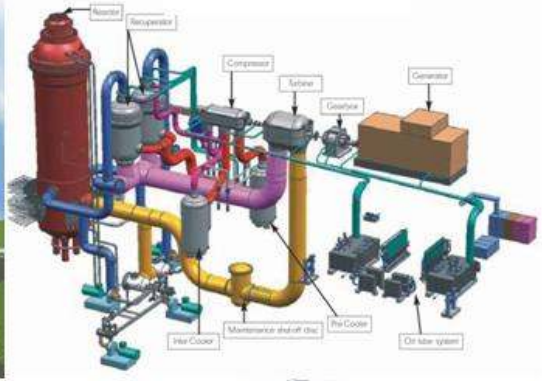
Variation in Electricity Tariffs

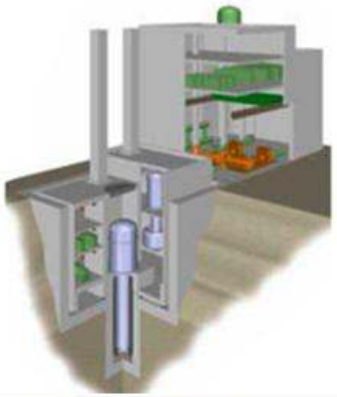


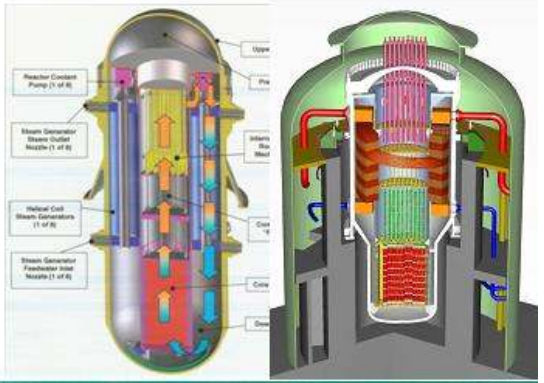
Expected Advantages of SMRs

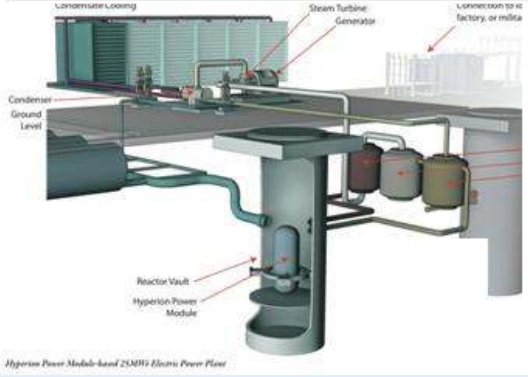
- Fitness for smaller electricity grids
- Options to match demand growth by incremental capacity increase
- Tolerance to grid instabilities
- Site flexibility
- Other possible advantages
  - Lower capital cost but perhaps higher capital cost per MWe
  - Shorter and more reliable construction
  - Easier financing scheme
  - Enhanced safety
  - Reduced complexity in design and human factors
  - Suitability for process heat application

Status of SMR Designs









Definition and SMR Developments in Member States

- Small-sized reactors: < 300 MW(e)
- Medium-sized reactors: < 700 MW(e)
  - Upper power limit may change as the current Large-sized is up to 1700 MW(e)
- Until recently, several dozens of Design Concepts of SMRs have been developed in **Argentina**, **China**, **India**, **Japan**, the **Republic of Korea**, **Russian Federation**, **South Africa**, **USA**, and several other IAEA Member States

Current SMR Designs

- **Light water-cooled SMRs *(iPWRs)*:**
  - **KLT-40, SMART, CAREM, IRIS, NuScale, mPower**
- **Heavy water-cooled SMRs:**
  - **EC-6/CANDU-6, PHWR 220**
- **Liquid metal-cooled fast reactors**
  - **PFBR-500, 4S, PRISM, Hyperion**
- **High-temperature gas-cooled reactors**
  - **CEFR, HTR-10, HTR-PM, PBMR, MHTGR**

SMRs – constructed, contracted or under construction

Heavy water cooled or moderated reactors	PHWR-220, 540, 700 (India), EC-6 (Canada)
Chinese PWRs	CNP-340, CNP-650
Russian PWRs	VVER-600, KLT-40
Fast Reactors	PFBR-500 (India), SVBR-100 (Russia)

SMRs – under development

Integral PWR type	NuScale, B&W's mPower, IRIS, CAREM, SMART, IMR
Other PWRs	ACP-600
Heavy water reactor	AHWR for Thorium utilization
Fast Reactors	4S, PRISM, BREST-400
Gas cooled reactors	PBMR, MHTGR
Other advanced reactors	Hyperion, DMS

Practical Questions to SMR deployment

- What are the pathways to license the being-developed SMRs? Regulatory infrastructure established?
- How soon a commercial product be available?
- How to prove economic competitiveness?
  - What are projected benefits against large plants? (how to overcome economy of scale?)
  - What will be the $/kWe; $/MWh?
- Have we done sufficient effort to assess GRID requirements in developing countries?
- How to identify operational issues? (based on lesson-learnt from operating large reactors)

Anticipated Challenges for SMRs

- Impact of economy of scale → competitiveness
- Licensability → delays due to design innovation
- Technological challenge (i.e. non LWR-SMRs)
- Infrastructure requirements
- Impact of innovative design and fuel cycle to proliferation resistance
- Reduced emergency planning zone
- Regulation for fuel or NPP leasing
- Limited market opportunities
- Yet unproven innovated technologies
- First-of-a-kind costs
- Availability of feasible designs for new entrants
- Limited technical benefits for recipient countries

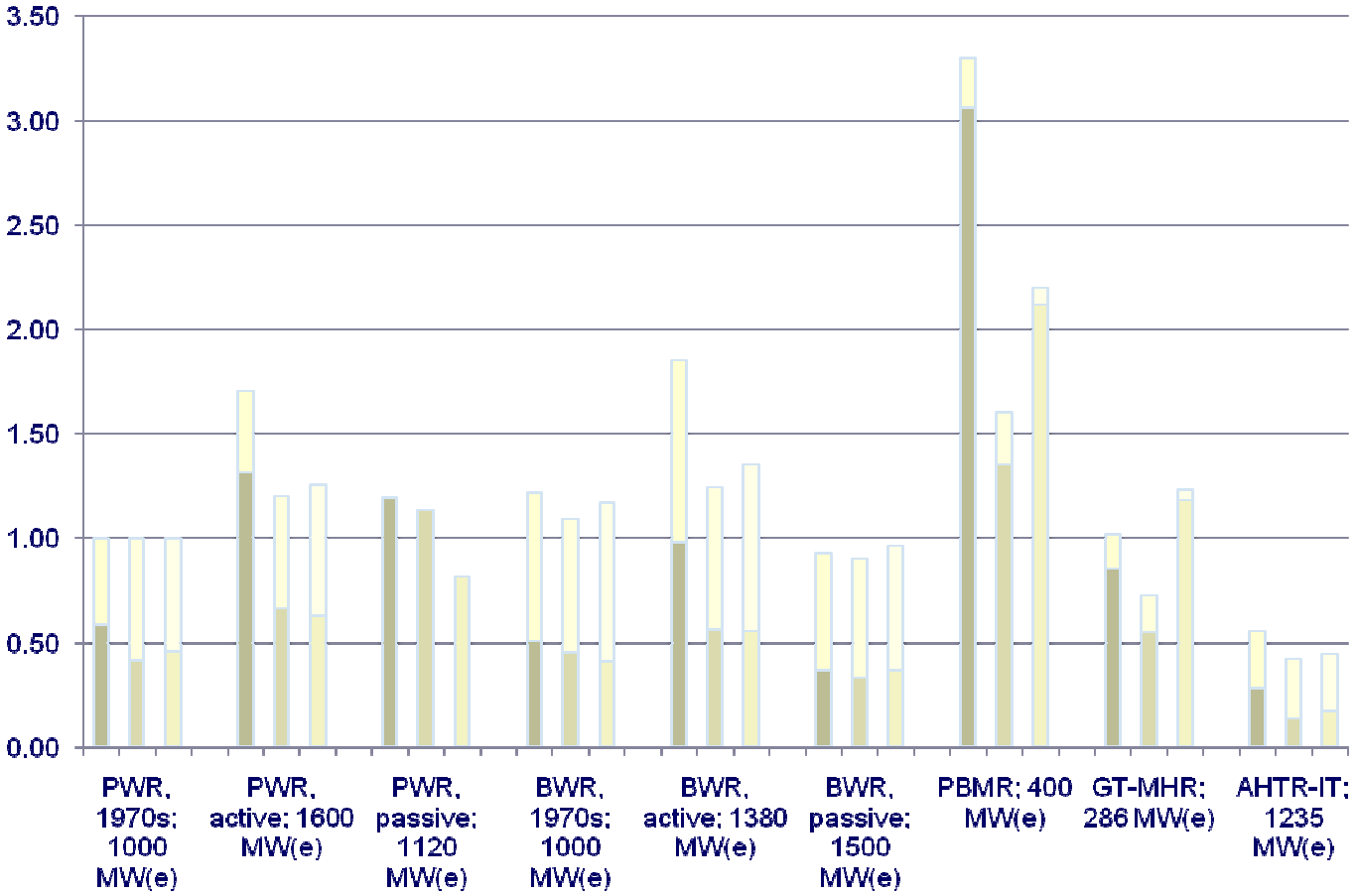
Trends in advanced plant design

- Increase plant availability
  - Use proven, reliable components and materials
  - Design for maintenance – online or during outage
  - Add redundancy for crucial components
- Reduce plant components – simplify
  - Use modern plant control systems
  - Use fewer and larger components
  - Combine or eliminate functions of systems
  - Rely on economy of scale
- Design for easier & shorter construction
  - Increased use of structural and system modules
  - Complete and standardized designs with pre-licensing
- Build safety into the design
  - Increased margins and use of lessons learned
  - Increase redundancy and diversity or use passive systems

Relying on 50 years of experience

Evolution of Technology
(Variation of material quantities over time)

Normalized quantities (per MW_e, relative to 1970s PWR)



1970s PWR:
-Building volume, total = 336 m^3/MW_e
-Steel mass, total = 37 t/MW_e
-Concrete volume, total = 75 m^3/MW_e

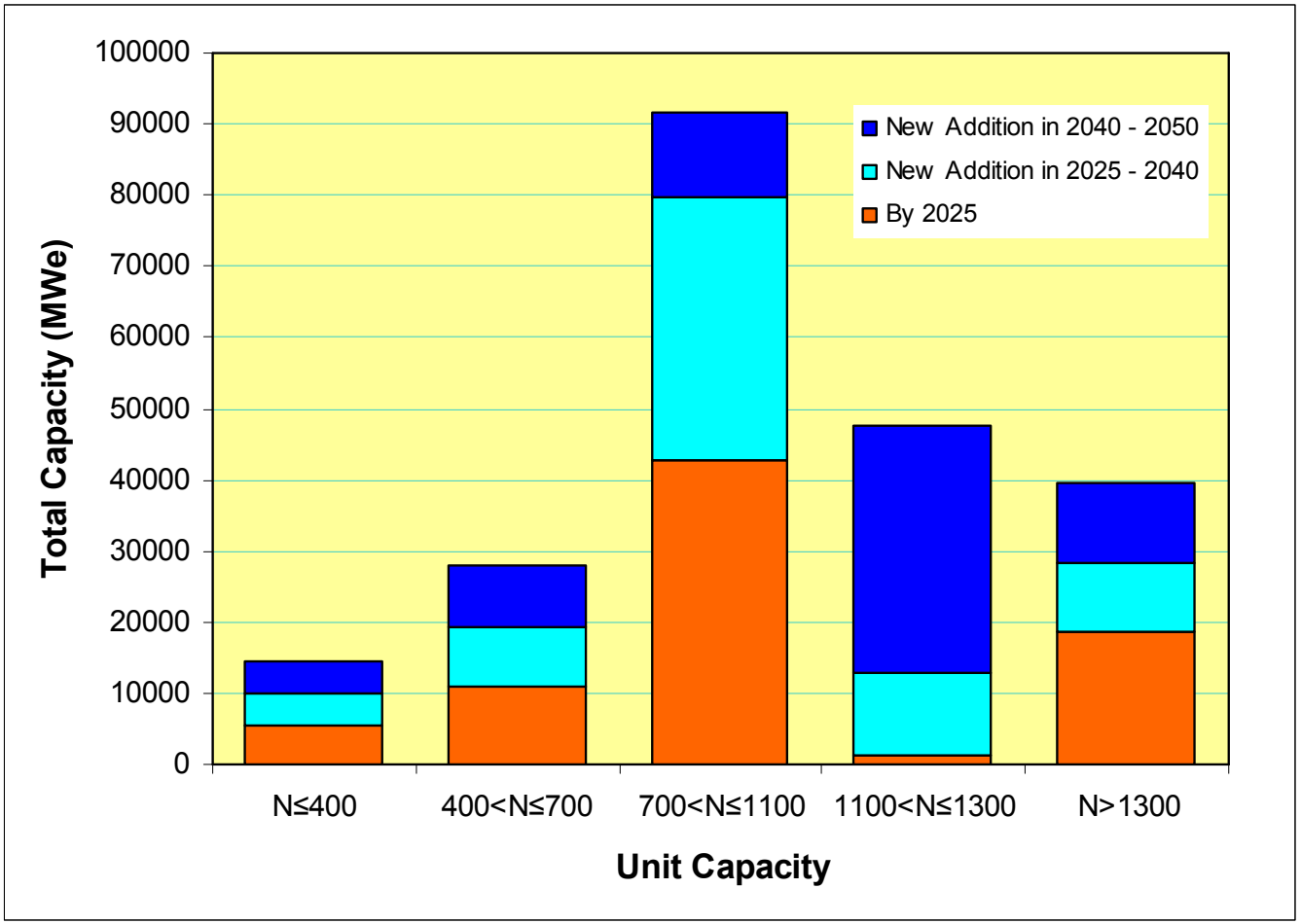
N.B. The passive PWR data are estimates based on available data. Values for the entire plant are plotted as "nuclear" in lieu of a "nuclear" and "non-nuclear" breakdown.

P.F. Peterson et al. "Metal and concrete inputs for several nuclear power plants"; Westinghouse & estimates

Generation Costs and Tariffs

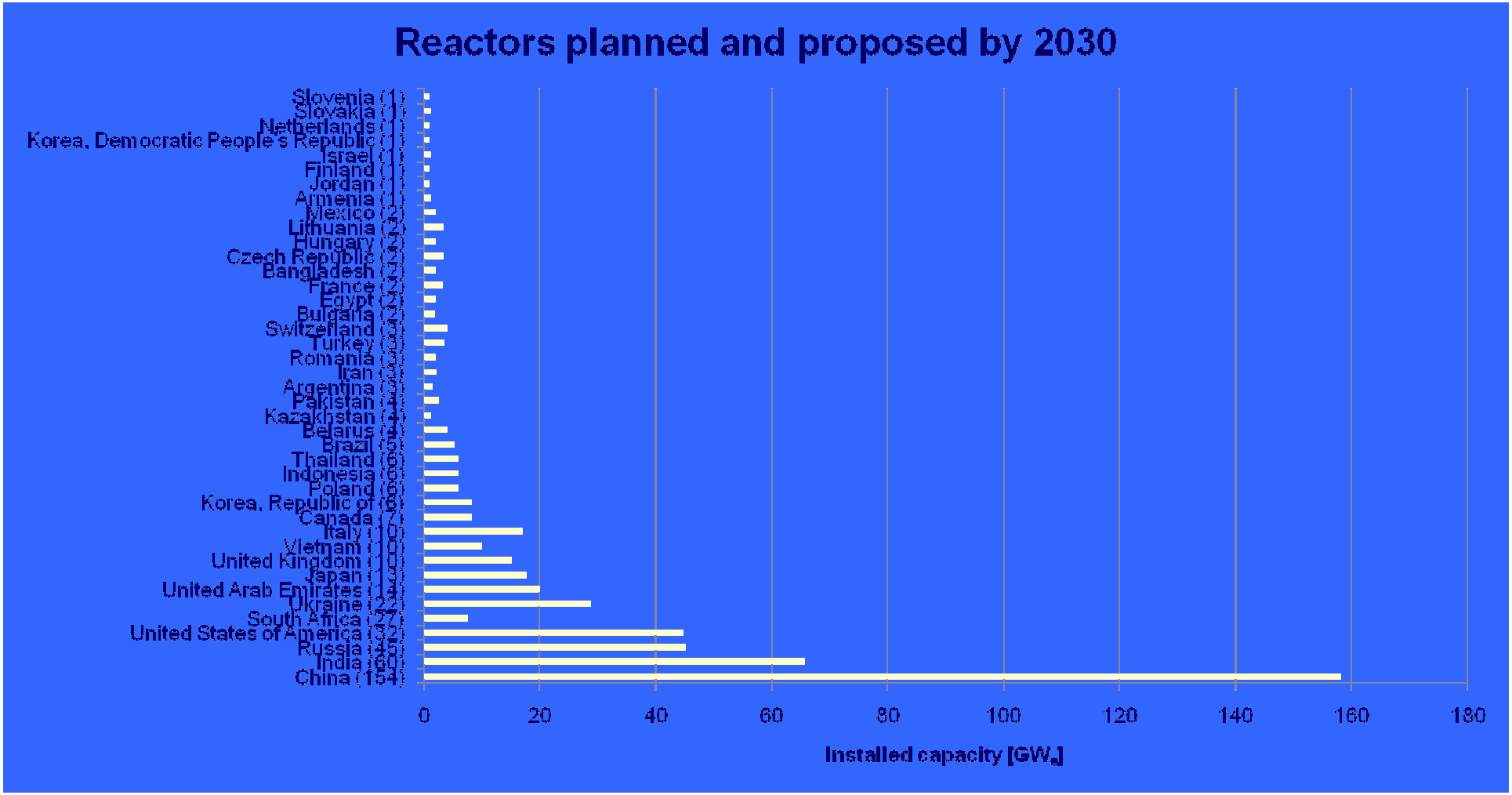
- Electricity generation costs for different options vary considerably across countries
- Economic evaluations need to consider generation, transmission and other costs
- Subsidies effect the costs (tariffs) paid by the consumers

Total new capacity at different unit sizes
(Expectations from "User" countries, derived from survey)



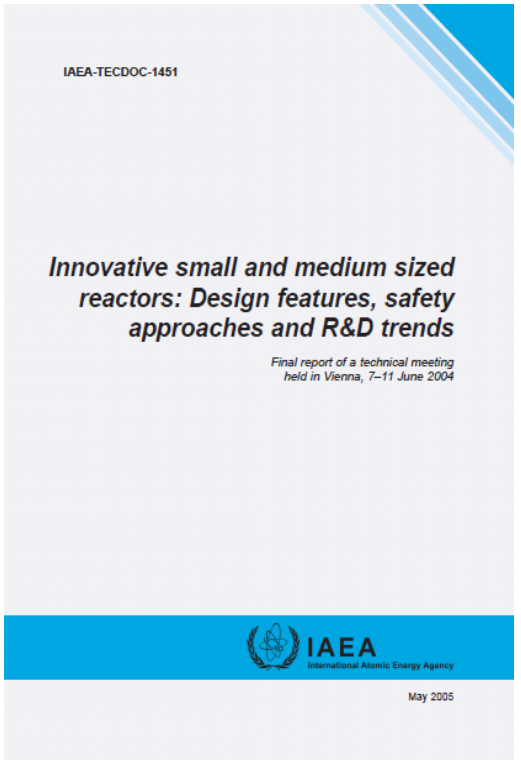
User Countries – 50 developing countries excluding China/India

NPPs planned & proposed by 2030



Source: WNA World Nuclear Reactors and Uranium Requirements; accessed May 2010

Project "Common Technologies and Issues for Small and Medium Sized Reactors (SMRs)"
P&B 2010-2013: 1.1.5.5



Objective:

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

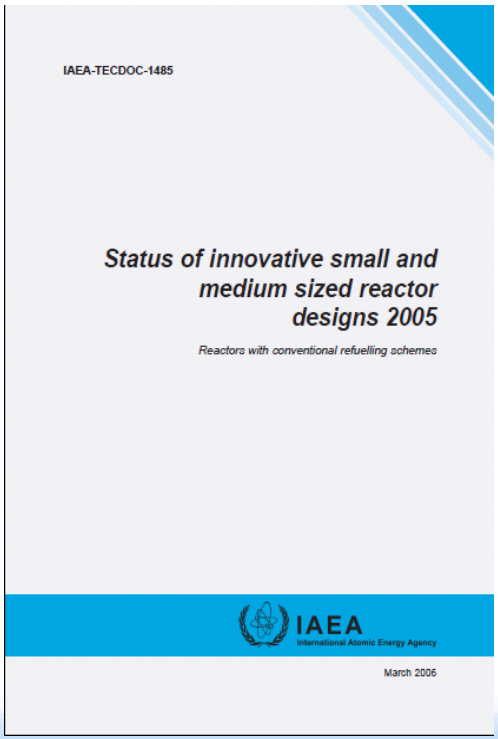
Expected outcome:

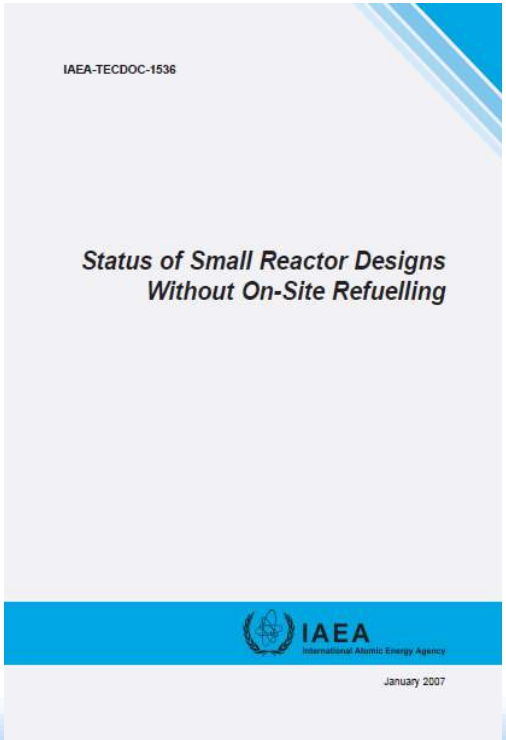
➢Increased international cooperation for the development of key enabling technologies and the resolution of enabling infrastructure issues common to future SMRs of various types

Status Reports of Advanced SMR Designs

- **INTERNATIONAL ATOMIC ENERGY AGENCY, Status of Innovative Small and Medium Sized Reactor Designs 2005: Reactors with Conventional Refuelling Schemes, IAEA-TECDOC-1485, Vienna (March 2006)**

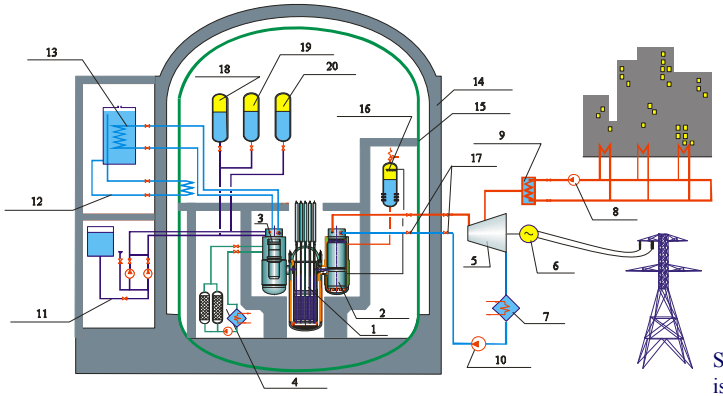
- **INTERNATIONAL ATOMIC ENERGY AGENCY, Status of Small Reactor Designs without On-site Refuelling, IAEA-TECDOC-1536, Vienna (March 2007)**

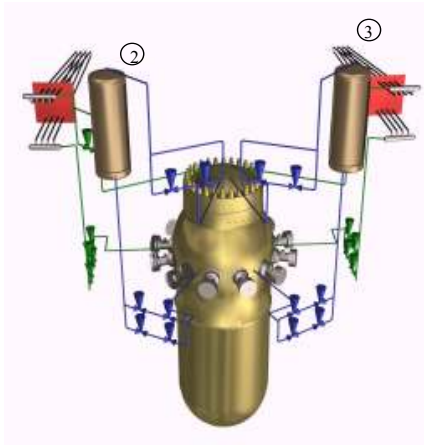


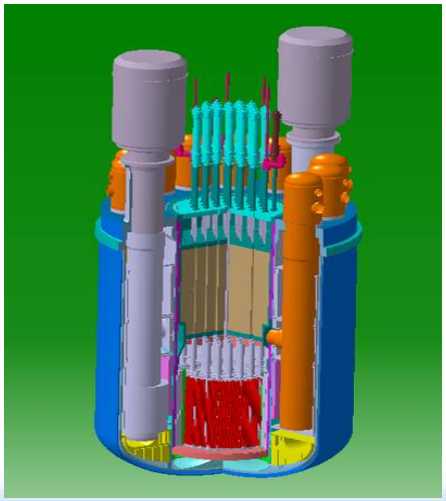


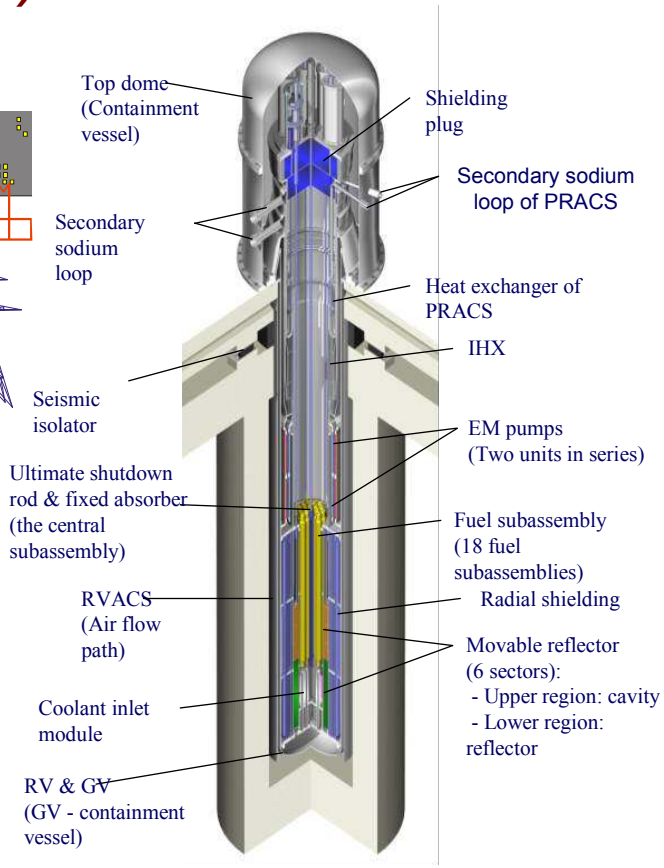
New Activity: SMR Design Descriptions for Advanced Reactor Information System (ARIS)

- ***Updating the Format for SMR design description***
- ***Design descriptions of advanced SMRs collected from Member States***
- ***Developing Database format and software (NPTDS)***



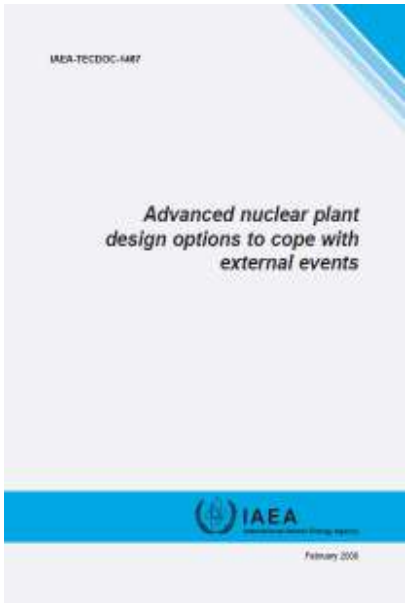


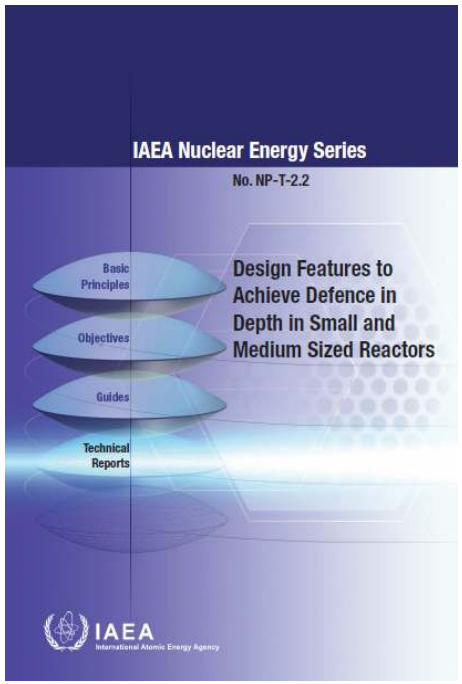




Selected Common Areas of Technology and Infrastructure Development in Support of Advanced SMRs

➢Design for External Events





➢Design Features to Achieve Defence in Depth in SMRs

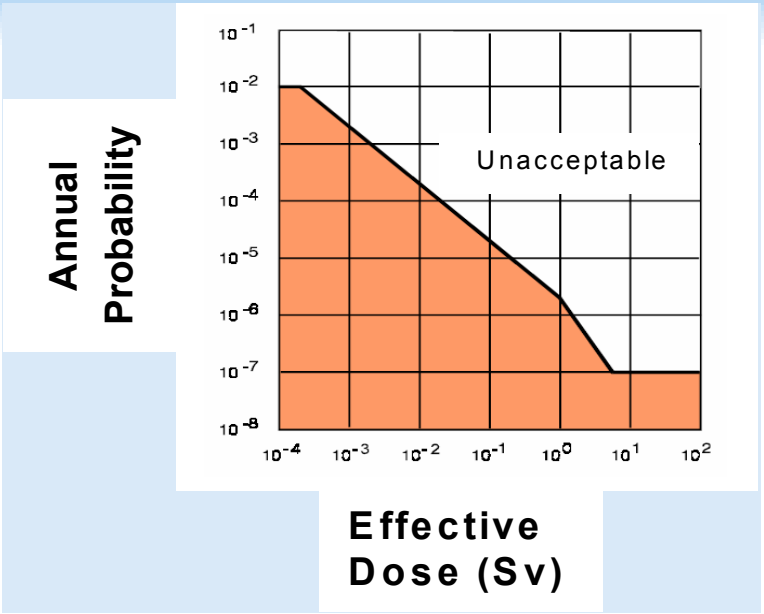
➢Methodology to Revise Emergency Planning Zone Requirements

✓**INTERNATIONAL ATOMIC ENERGY AGENCY, Final Report of a CRP on Small Reactors Without On-site Refuelling, IAEA-TECDOC (Published in 2010)**

Risk-Informed Approaches

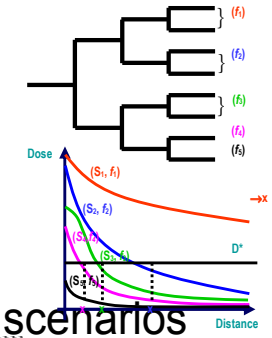
Risk-informed Methodology to redefine EPZ . The requirements has been developed within IAEA CRP "Small Reactors without On-site Refuelling" (2004-2009)

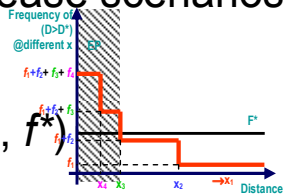
Argentina's regulations (severe accidents)

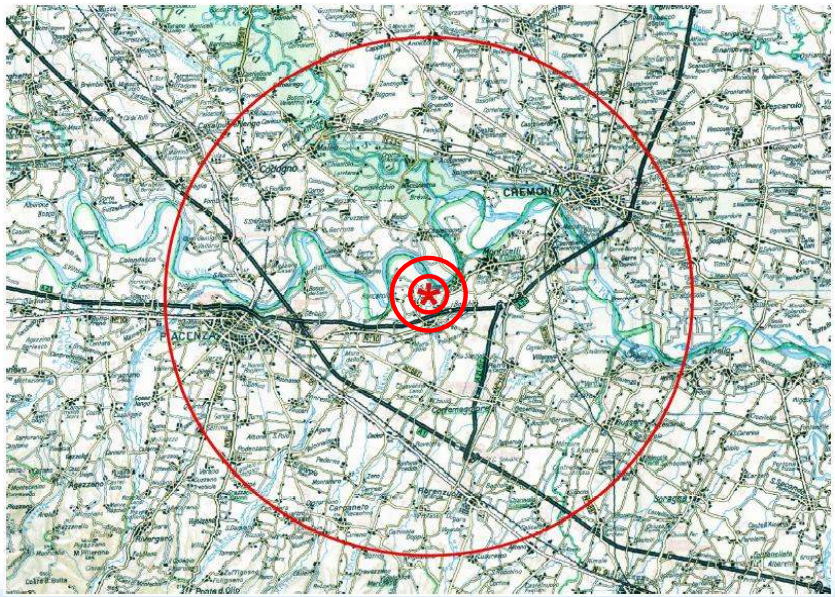


EPZ Redefinition Methodology

- 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)

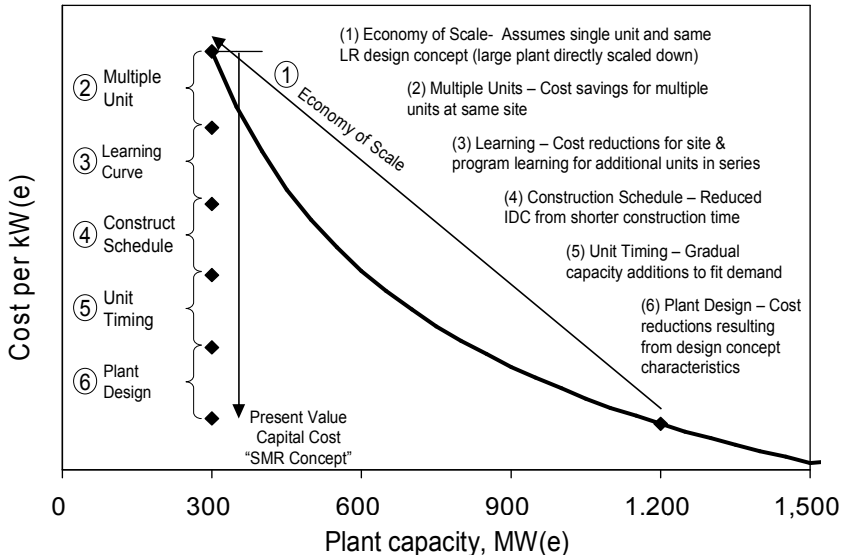






Selected Common Areas of Technology and Infrastructure Development in Support of Advanced SMRs

➢Approaches and Tools to Assess Competitiveness of SMRs



Note 1 - IDC: Interest during construction

FIG. 8. Generic view of factors affecting comparative costs of SMRs and large reactors.

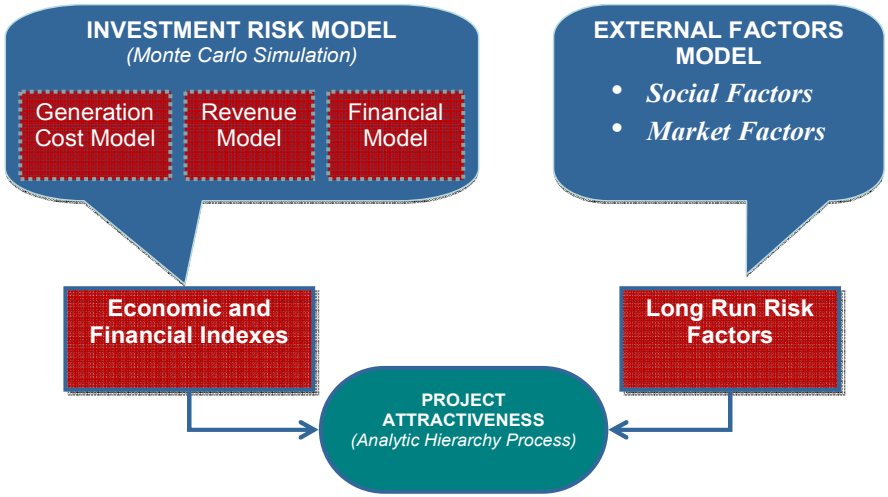


FIG. 14. Schematics of the integrated model for competitiveness assessment of SMRs (INCAS, Politecnico di Milano, Italy)

✓INTERNATIONAL ATOMIC ENERGY AGENCY, Approaches to Assess Competitiveness of SMRs, Nuclear Energy Series Report (to be published in early 2011)

➢Options to Enhance Proliferation Resistance and Physical Protection of NPPs with Innovative SMRs

✓Multiplicity of SMRs or their remote location may pose proliferation resistance and physical protection challenges

✓A report will be developed to provide a framework for the application of PR &PP assessment methodologies to evaluate PR&PP features of innovative SMRs and associated fuel cycles beginning in the early design stages and, progressively, as the design matures

The Technical Meeting was held on 8 – 11 June 2010 at the IAEA - Vienna

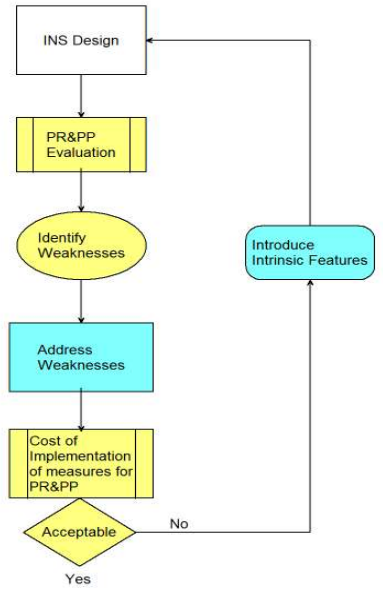


Fig. 1. General framework of the proliferation resistance and physical protection assessment at different design stages of an innovative SMR and associated fuel cycle.

CRPI31018 "Development of Methodologies for the Assessment of Passive Safety System Performance in Advanced Reactors" (2009-2011)

In Conjunction with Technical Working Groups on Advanced Reactors
- Nuclear Power Technology Development Section of the NE, and
- Safety Assessment Section of the NS

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

The 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.

CRP I31018 "Development of Methodologies for the Assessment of Passive Safety System Performance in Advanced Reactors"

➢**The participants are:**

CNEA (Argentina)
BARC (India)
IGCAR (India)
CEA (France)
ENEA (Italy)
University of Pisa (Italy)
OKB "Gidropress" (Russia)
Idaho State University (USA)

+ Observers from Japan and Sweden

➢First Research Coordination Meeting (RCM-1) was convened on 31 March - 3 April 2009 at the IAEA, Vienna.

➢Detailed work plan and schedule for 2009 - early 2010 was defined and implemented

➢Second RCM was held at the IAEA on 16 – 19 March 2010

SUMMARIES

- SMRs may provide an attractive and affordable nuclear power option for developing countries with small electrical grids, insufficient infrastructure and limited investment capability
- Multi-module power plants with SMRs may offer energy production flexibility in the current and future deregulated energy market
- SMRs are of particular interest for co-generation and many advanced future process heat applications
- SMR designs may reduce challenges on spent fuel and waste management and offer greater non-proliferation assurances to the international community
- The Innovative SMR concepts have several common technology development issues related to licensability, economic competitiveness, plant-siting, optimum financing scheme, proliferation resistance and security, long refueling interval and operation without on-site refueling

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