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Joint ICTP-IAEA School of Nuclear Energy Management

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IAEA Project on Common Technology and Issues for Small and Medium-sized Reactors

Mohammad Hadid Subki

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Austria

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IAEA Project on Common Technology and Issues for Small and Medium-sized Reactors

M. Hadid Subki
Technical Lead, SMR Technology

Nuclear Power Technology Development Section
Nuclear Division of Nuclear Power

Department of Nuclear Energy

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Outline

- Global Status of SMR Deployment and Development
- Status of SMR designs
- Perceived Advantages and Challenges
- Generic Technical Issues
- Developing Countries' Expectations
- Lessons-Learned from the Fukushima Event
- Conclusions

Numerous SMR Designs at Various stages

LWRs
- ABV
- CAREM
- CPR-300
- IRIS

LWRs
- KLT-40S
- mPower
- MRX
- NHR-200

LWRs
- NP-300
- NuScale
- RITM-200
- SMART

LWRs
- VBER-150
- VBER-300
- VK-100/300
- SMR-200

FRs
- 4S
- BREST-300
- HPM
- SVBR-75/100

FRs
- LSPR
- PFBR-500
- PRISM
- ENHS

iPWRs
- VKT-12
- FBNR
- IMR
- Flexblue

PHWRs
- AHWR
- CANDU-6
- PHWR-220
- PHWR-540

GCRs
- HTR-PM
- EM^2
- GT-MHR
- PBMR

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Definitions

- IAEA:
  - Small-sized reactors: < 300 MW(e)
  - Medium-sized reactors: 300 → 700 MW(e)
  - Regardless of being modular or non-modular
  - Covers all reactors in-operation and under-development with power < 700 MWe
  - Covers 1970s technology → 2000s innovative technology
- Several developed countries:
  - Small-sized reactors: < 300 MW(e)
  - Emphasize the benefits of being small and modular
  - Focus on innovative reactor designs under-development

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Global Development and Deployment

- Dozens of concepts for innovative SMRs are under development in many IAEA Member States:
  - Argentina, Brazil, Canada, China, France, India, Japan, Republic of Korea, Russia, South Africa, USA, and some emerging countries.
- A number of companies are developing SMRs; each has unique features and varying megawatt capacity.
- Many SMRs (with 1970s, 1980s technologies) have long been in operation and many are under construction

In Operation	**125**
Under construction	**17**
Number of countries with SMRs	28
Generating Capacity, GW(e)	57.1

- None of the <u>innovative</u> SMRs are commercially available

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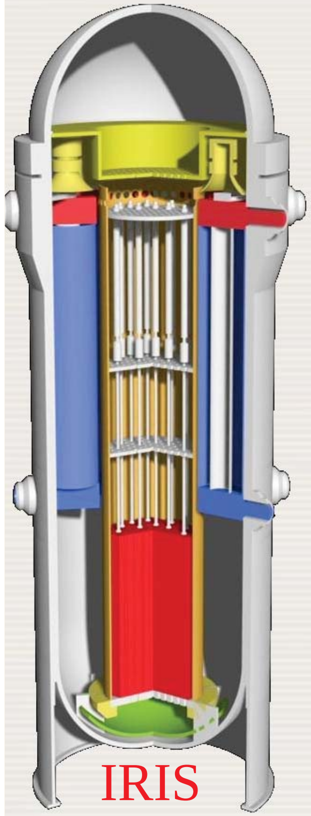
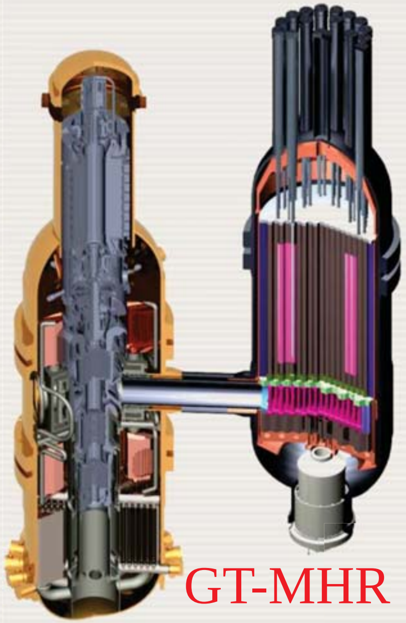
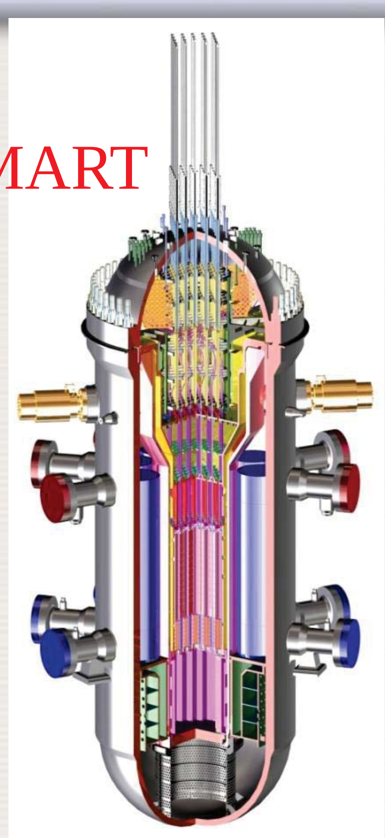
Contemporary SMR designs represent evolution from designs of the 70s, 80s, 90s…

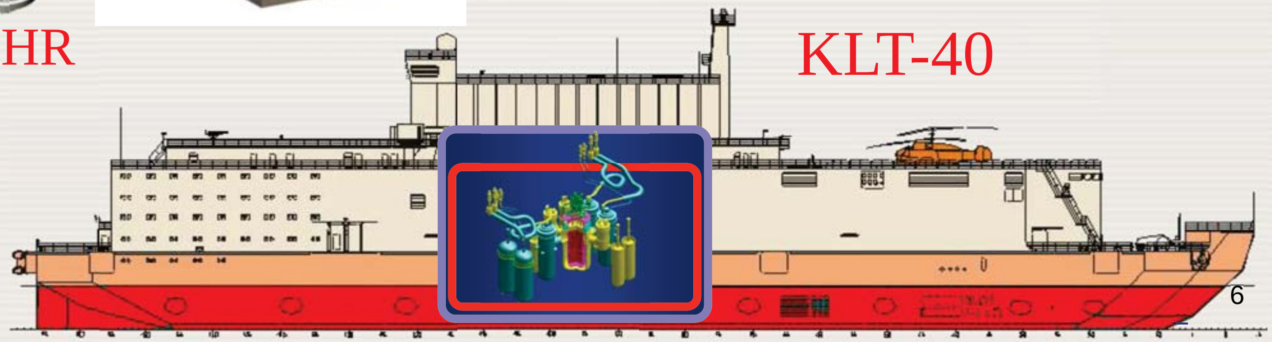

IRIS


GT-MHR

NuScale


SMART



mPower

KLT-40


SMRs for Immediate Deployment

	Name	Design Organization	Country of Origin	Electrical Capacity, Mwe	Design Status
1	Pressurized Heavy Water Reactor (PHWR-220)	NPCIL	India	220	16 units in operation
2	PHWR-540	NPCIL	India	540	2 units in operation
3	PHWR-700	NPCIL	India	700	4 units under construction
4	KLT-40S	OKBM	Russian Federation	70	2 units under construction
5	HTR-PM	Tsinghua University	China, Republic of	250	Detailed design, 2 modules under construction
6	Central Argentina de Elementos Modulares (CAREM)	INCAP-CNEA	Argentina	27	Detailed design, prototype construction in 2012
7	Prototype Fast Breed Reactor (PFBR-500)	IGCAR	India	500	Under construction – Commissioning in 2012
8	CANDU 6	Atomic Energy of Canada Limited	Canada	700	Many in operation
9	CPR-300	CGNPP	China, Republic of	300	1 unit in Operation as Chasnupp-2 in Pakistan

SMRs for Near-term Deployment

	Name	Design Organization	Country of Origin	Electrical Capacity, MWe	Design Status
1	System Integrated Modular Advanced Reactor (SMART)	Korea Atomic Energy Research Institute	Republic of Korea	100	Detailed design
2	NuScale	NuScale Power	United States of America	45/module	Detailed design, to apply for certification in January 2012
3	mPower	Babcock & Wilcox	United States of America	125/module	Detailed design, to apply for certification later in 2012
4	VBER-300	OKBM	Russian Federation	300	Detailed design
5	SVBR-100	Rosatom	Russian Federation	100	Detailed design for prototype construction
6	Westinghouse SMR	Westinghouse	United States of America	200	Detailed Design
7	Super-Safe, Small and Simple (4S)	Toshiba-CRIEPI	Japan	10	Detailed design
8	Pebble Bed Modular Reactor (PBMR)	ESKOM	South Africa	100	Detailed design; Development discontinued

Example of SMRs for Long-term Deployment

	Name	Design Organization	Country of Origin	Electrical Capacity, MWe	Design Status
1	Power Reactor Innovative Small Modular (PRISM)	GE Hitachi	United States of America	311	Detailed Design
2	Advanced Heavy Water Reactor	BARC	India	220	Conceptual Design
3	Integrated Modular Water Reactor (IMR)	Mitsubishi Heavy Industries	Japan	350	Conceptual Design
4	Flexblue	AREVA, EDF, DCNS, CEA	France	50-250	Conceptual Design
5	VK-300	RIAR	Russian Federation	100/300	Conceptual Design
6	EM^2	General Atomics	USA	240	Conceptual Design

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Perceived Advantages and Challenges

	Advantages	Challenges
Technological Issues	• Shorter construction period (modularization) • Potential for enhanced reliability and/or safety • Reduced complexity in design and human factor • Suitability for non-electricity application (i.e. process heat and desalination) • Tolerance to grid instabilities	• Licensability (delays due to design innovation) • Non-LWR technologies • Impact of innovative design and fuel cycle to proliferation resistance • Operability • Spent fuel management and waste handling policies
Non-Technological Issues	• Fitness for smaller electricity grids • Options to match demand growth by incremental capacity increase • Site Flexibility • Lower upfront investment capital cost per installed unit • Easier financing scheme	• Economic competitiveness (impact of economy of scale) • Reduced emergency planning zone • Regulation for fuel or NPP leasing • Limited market opportunities • First of a kind cost estimate • Availability of design for newcomers • Infrastructure requirements

Answers Needed Prior to Deployment

- What are the pathways to licensing?
- How soon will a commercial product be available?
- How to prove economic competitiveness?
  - What are projected benefits against large plants? (multi-modules SMR vs single large unit)
  - What are projected benefits against fossil power plants with the same power output?
  - What will be the realistic $/kWe delivered?
- Are the grid requirements in developing countries understood and can the technology being offered meet them?
- What operational issues are expected and how will they be addressed?

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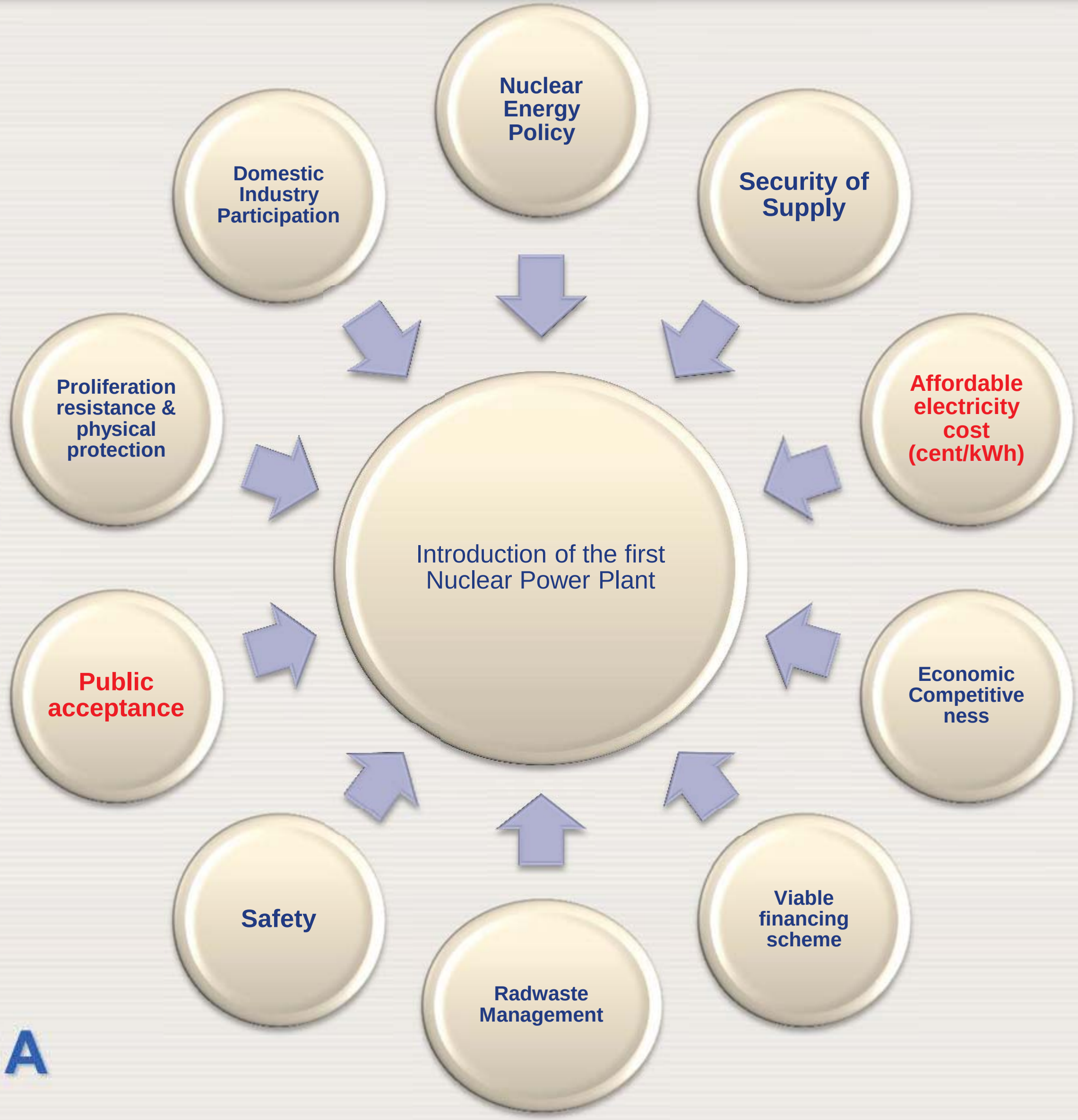
Generic Technical Issues

- First of a kind engineering
- Innovative fuel/core design and fuel cycle
- Viability of multiple-modules station (post-Fukushima)
- Proliferation resistance and physical security
- Ergonomics and control room staffing
- Emergency planning zone
- Mechanistic source term
- Standardization and licenses for manufacturing
- Technology transfer and proprietary design protection
- Users and Owners issues

Developing Countries Expectations



IAEA Response to the Global Trend

- **Project 1.1.5.5:** Common Technologies and Issues for SMRs (P&B 2010 – 2011 and 2012 – 2013)
- **Objective:** To facilitate the development of key enabling technologies and the resolution of enabling infrastructure issues common to future SMRs
- **Activities:**
  - Formulate roadmap for technology development
  - Review newcomer countries requirements, regulatory infrastructure and business issues
  - Define operability-performance, maintainability and constructability indicators
  - Develop guidance to facilitate countries with planning for SMRs technology implementation

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IAEA's Project 1.1.5.5 (2010 - 2011)

- Consultancy Meeting on "Status of Innovative SMR Designs with a Potential of Being Deployed by 2020"
  - Date/place: **2 - 4 May** 2011 in IAEA – Vienna (DONE)
- Research Coordination Meeting for the CRP on "Development of Advanced Methodologies for the Assessment of Passive Safety System Performance in Advanced Reactors (I31018)"
  - Date/place: 26 - 28 April 2011 in IAEA – Vienna (DONE)
- TC - Workshop on Advanced Nuclear Reactor Technology for Near Term Deployment
  - Date/place: 4-8 July 2011 in IAEA – Vienna (DONE)
- 3rd Technical Meeting on "Options to Incorporate Intrinsic Proliferation Resistance Features to NPPs with Innovative SMRs"
  - Date/place: **15 - 18 August** 2011 in IAEA – Vienna (…next week !!!)
- CM on "Options to Enhance Energy Supply Security with NPPs based on SMRs"
  - Date/place: 3 -6 October 2011 in IAEA – Vienna
- Workshop on "Technology Assessment of SMR deployable by 2020"
  - Date/place: 5 – 9 December 2011 in IAEA – Vienna
  - Extra-budgetary from Republic of Korea

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Conclusions

- **SMR** is an **attractive nuclear power option for developing countries** with small electricity grids and less-developed infrastructure
- Potential for **near-term deployment** but much work yet to be done by stake holders
- Innovative SMR concepts have **common technology development challenges**: licensability, competitiveness, financing schemes, newcomer countries requirements
- **Economics**: $ per kWe to construct? $ per kWe-hr to operate?
- Needs to implement **lessons-learned from the Fukushima Accident** into the design, safety, economic, financial, licensing, and public acceptance for SMRs

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… Thank you for your attention.

For inquiries, please contact:
Dr. M. Hadid Subki <M.Subki@iaea.org>