بسم الله الرحمن الرحيم

إنا كل شيء خلقناه بقدر

PAE

Pakistan Academy of Engineering

Proceedings of the
10th Symposium of
the Pakistan Academy of Engineering

"PROSPECTS OF MINI NUCLEAR POWER PLANTS IN PAKISTAN"

Held on April 28, 2018
at Mövenpick Hotel, Karachi - Pakistan

Contents

1. Message from the President

My Dear Fellows and Readers,

اَلسَّلَامُ عَلَيْكُمْ وَرَحْمَةُ اللهِ وَبَرَكَاتُهُ

With the great feeling of accomplishment and satisfaction, on behalf of the Pakistan Academy of Engineering (PAE), I present to you the proceedings of the 10th Symposium of PAE on the topic of "Prospects of Mini Nuclear Power Plants in Pakistan", held on April 28, 2018, at Mövenpick Hotel, Karachi.

First I would like to thank Mr. Muhammad Naeem (H.I., S.I., Chairman, Pakistan Atomic Energy Commission, PAEC) who assigned Mr. Saeed Alam Siddiqi (Member Chairman's Advisory Council, PAEC). I would also like to thank Mr. Jamshed Azim Hashmi (Chief Engineer (Retd), PAEC & Chairman Emeritus, PNRA), Mr. Javed Iqleem (Member Power (Retd), PAEC), Mr. Waqar Murtaza Butt (Member Engineering (Retd), PAEC, S.I., T.I.), Mr. Hidayatullah Khan (Manager SMR Technology, PAEC) and Engr. Mohammad Irshad (PE, Consultant Nuclear Power Plants, Lincon, California, USA) for their presentations in the 10th Symposium of PAE. I hope the Engineering & Scientific community along with the members of legislature and government will find the insightful presentations useful as suggestions for the future development of Pakistan.

Secondly, my sincere thanks to the Pakistan Science Foundation (PSF), Principal Builders and Ravian Maritime (Pvt.) Ltd. for providing sponsorship support.

Here I would also acknowledge the support of the Trustees of Pakistan Academy of Engineering - Endowment Fund (PAE-EF) and Council members & Staff of the Pakistan Academy of Engineering (PAE) for their relentless support and assistance.

Finally, I hope that the readers will find the document useful and will gain knowledge and insight in the context of this complex and critical topic.

Very sincerely yours,

Dr.-Ing. Jameel Ahmad Khan
President,
The Pakistan Academy of Engineering (PAE)

2. Programme of the 10th Symposium

Programme
Symposium: "Prospects of Mini Nuclear Power Plants in Pakistan"
April 28, 2018
Mövenpick Hotel, Karachi

- Arrivals of Guests : 09^{30} hrs
- Guests to be seated : 09^{45} hrs
- Recitation from the Holy Quran : 10^{00} hrs
- Welcome Address by the President PAE : 10^{05} hrs

PRESENTATIONS

1. Keynote Address: Role of Nuclear Power in Pakistan with Emphasis on Small Modular Reactors (SMRs) : 10^{10} hrs
   by Mr. Muhammad Naeem, H.I., S.I.,
   Chairman, Pakistan Atomic Energy Commission

2. Small Modular Reactors (SMRs): : 10^{55} hrs
   Duplication of KANUPP Incorporating
   Current SMR Applications, Technology & SMR Features
   by Mr. Jamshed Hashmi,
   Chairman, Emeritus PNRA
   Mr. Javed Iqleem,
   Member Power (Retd.) PAEC
   Mr. Waqar Butt,
   Member Engineering (Retd.) PAEC, S.I., T.I.

   - Coffee Break : 11^{40} hrs

3. The Lessons Learned in the Development of Nuclear Plants in the USA : 11^{55} hrs
   by Engr. Mohammad Irshad, PE,
   Consultant Nuclear Power Plants,
   Lincon, California, USA

- Discussion by the Participants : 12^{40} hrs
- Concluding observations : 12^{55} hrs
- Lunch : 13^{10} hrs

3. Presentations as per Programme

3.1. Welcome Address of 10th Symposium
by
President PAE, Dr.-Ing. Jameel Ahmad Khan

My dear Fellow Engineers!

Ladies & Gentlemen!

Assalam-o-Alaikum

Welcome to all!

This is our 10th Symposium. During the last four years of our existence we have brought to your kind attention themes not discussed elsewhere in the country. Pakistan Academy of Engineering is a thinking laboratory.
Our sincere gratitude that you have graced this morning an event of great significance. The map on the screen provides sufficient evidence of the crucial importance of the Mini, Small and Medium Size Nuclear Power Reactors that all the developed countries have assigned. According to the Nuclear Industries Association (NIA), UK the potential global SMR market is valued at £250-400 billion by 2035.

Size matters. The detailed advantages of the Mini and SMRs will be discussed by the speakers. However it will be interesting to describe briefly their attributes:

- Distributed power generation with the Mini & SMRs eliminates reliance on a robust transmission grid.
- Benefits of series production of Nuclear Plants in the factories, and their modularity will sink costs.
- Mini and SMRs will enable achieve carbon reduction targets.
- The timeline for installation of Mini and SMRs is short.

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3.1. Welcome Address of 10th Symposium
by President PAE, Dr.-Ing. Jameel Ahmad Khan, continued... ▶▶▶

Ladies and Gentlemen!

Energy production is surging globally. 17 trillion kWh of electricity is produced every year. 90 million barrels of Oil is burnt each day. These number will double in the next 25 years. We have to develop energy strategies to power our future. Quality of life depends upon electric power. Human beings need at least 3000 kWh per year for good life.
Our last 50 years experience proves that Nuclear Power is the safest and most efficient of all energy sources. Extreme energy density of Nuclear Power is the key to our global energy solution.

Toxic waste generated by a 1000 MW Coal Plant is 10 times as voluminous as the waste generated from a 1000 MW Nuclear Power Plant. CO_2 emitted from Coal Power Plant is almost 100 times greater than that of Nuclear Power Plant. 1000 MW Nuclear Plant requires one square mile while 10,000 one MW Wind Turbines need 15,000 square miles for installation. The actual lifetime cost of Nuclear Energy is second lowest i.e. next to the Hydroelectric.

Primary energy supplies to Pakistan during the year 2015-2016 amounted to about 74 million TOE. Nuclear, hydel and imported electricity constituted only 13.3%. Energy consumption of 45 million TOE had an electricity component of 16.2%. The installed capacity of power generation is about 26 GW. The Nuclear Power Capacity is 750 MW. There is a deficit of 5000 to 7000 MW in the generation capacity to meet the demand. The per Capita consumption of electricity in Pakistan is about 435 kWh, well below the good life figure of 3000 kWh.

The World Nuclear Association defines the SMRs as nuclear reactors generating 300 MWe equivalent or less, designed with modular technology using modular factory fabrication, pressing economies of series production and short construction times. The largest experience operating nuclear power plants has been in nuclear naval propulsion, potentially submarines. The nuclear powered vessels comprise about 40% of the USA Navy's Combatant fleet.

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The interest in small and medium nuclear power reactors is driven by the key desire to reduce the impact of capital costs and to provide power away from the large grid systems. A subscategory of very small reactors (VSMRs) is proposed for units under about 15 MWe, specially for remote communities.

Here are some interesting facts:

- Ontario Ministry of Energy, Canada, has focused on nine designs under 25 MWe for off-grid remote sites.
- Four Units of 62 MWe are already operating in a remote corner of Siberia (Bilibino), Russia.
- Japan Atomic Energy Research Institute designed a small (50 – 300 MWe) reactor for marine propulsion or local energy supply.
- Technicatome (Arena TA) in France has developed a 300 PWR for submarine power and for export for power, heat and desalination.
- Chinese institute of Nuclear and New Energy Technology designed and commissioned a 200 MWe unit for district heating and desalination in 1989.
- Korean Atomic Energy Research Institute (KAERI) signed an Agreement with Saudi Arabia's King Abdullah City of Atomic and Renewable Energy (KA – CARE) in March 2015, to assess the potential for building smart reactors. Further agreements to that end were signed in September 2015. The cost of building the first SMART unit for Saudi Arabia was estimated at US $ 1 billion. SMART is a 330 MWt PRW reactor. The unit is designed for electricity generation (up to 100 MWe) as well as thermal application, such as seawater desalination. A 2010 royal decrie identified nuclear power as essential to help meet growing energy demand for both electricity generation and water desalination, while reducing reliance on depleting hydrocarbon resources.

The National Transmission and Distribution Company (NTDC) operates and maintains 16 500 kV and 39 220 kV grid stations, 5301 km of 500 kV transmission line and 10,148 km of 220 kV line in Pakistan. However, only 50% of the population has access to electricity. The spread of our electric grid system is limited. Therefore, off-grid distributed

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power systems are the best answer to enhance access to electricity. The Mini and Small Nuclear Power Plant merit serious consideration as suitable candidates along with renewable sources of energy. Design & construction capability has to be indigenized.

Ladies & Gentlemen!

We would like to express our sincere thanks to Mr. Muhammad Naeem, HI, SI, Chairman of the Pakistan Atomic Energy Commission (PAEC), who readily accepted our request to deliver the Keynote Address on the theme this morning. Regretfully, he could not attend on account of an emergent meeting. Engr. Saeed Alam Siddiqi, Member, Chairman's Advisory Council, PAEC, will be performing on his behalf.

We also express our gratitude to Engr. Jamshed Hashmi, ex-chairman of the PNRA and his colleagues Mr. Javed Iqleem, Member Power (Retd.) PAEC, and Mr. Waqar Butt, Member Engineering (Retd.) PAEC, S.I., T.I., to make their valuable presentation.

We are grateful to Engr. Mohammad Irshad, a respected specialist in nuclear plant design and construction, to give the benefit of his experience to our audience.

We acknowledge with thanks the messages received from Mr. Yakiyo Amano, Director General, International Atomic Energy Agency. The message reads: "I wish you all the very best for this important event and for the future.", and from Mr. Jaejoo Ha, President, Korea Atomic Energy Research Institute. His message reads: "Even though I cannot avail myself of this opportunity to attend this Conference , I do hope it will be of great success."

Thank you, Ladies & Gentlemen!

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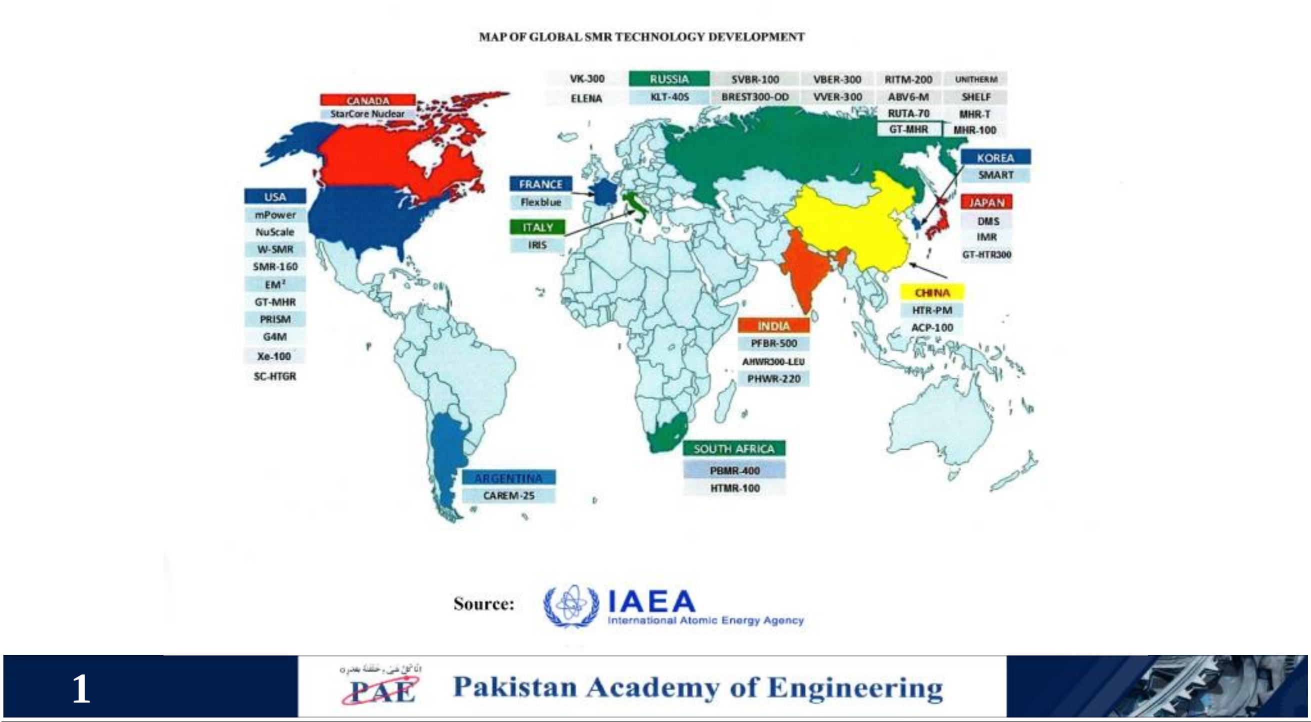
Slides of the Welcome Address



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Very small reactor designs being developed (up to 25 MWe)

S.No.	Name	Capacity	Type	Developer
1.	U-battery	4 MWe	HTR	Urenco-led consortium, UK
2.	Starcore	10-20 Mwe	HTR	Starcore, Quebec
3.	USNC MMR-5&10	5 MWe	HTR	UltraSafe Nuclear, USA
4.	Gen4 module	25 MWe	Lead-bismuth FNR	Gen4 (Hyperion), USA
5.	Sealer	3-10 Mwe	Lead FNR	LeadCold, Sweden

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Table 1. Power deficit during peak hours in the Pakistan power system (NTDC + K-Electric), 2006-2016

FY	Installed capacity (MW)	Maximum generation capability (MW)	Demand during peak hours (MW)	Deficit (MW)
2006	19 550	15 168	15 223	-55
2007	19 681	15 575	17 487	-1 912
2008	20 232	14 707	19 281	-4 574
2009	20 556	16 040	20 314	-4 274
2010	21 614	15 144	21 029	-5 885
2011	23 342	15 430	21 086	-5 656
2012	23 487	15 896	22 654	-6 758
2013	23 725	16 846	21 605	-4 759
2014	23 702	18 771	23 505	-4 734
2015	24 961	19 132	24 757	-5 625
2016	25 374	20 121	25 754	-5 633

Sources: NEPRA (2015a) *State of Industry Report 2014*; NEPRA (2016a), *State of Industry Report 2015*

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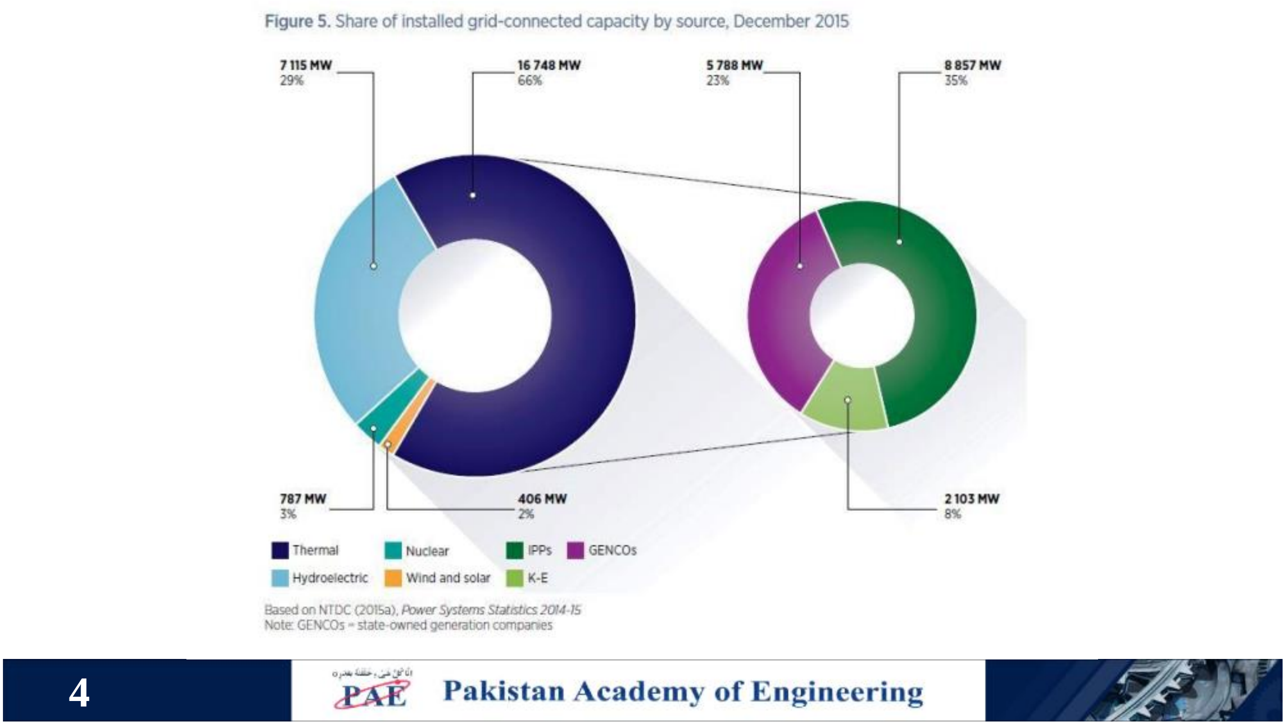
Figure 5. Share of installed grid-connected capacity by source, December 2015
7 115 MW
29%
16 748 MW
66%
5 788 MW
23%
8 857 MW
35%
787 MW
3%
406 MW
2%
2 103 MW
8%
Thermal
Hydroelectric
Nuclear
Wind and solar
IPPs
K-E
GENCOs
Based on NTDC (2015a), Power Systems Statistics 2014-15
Note: GENCOs = state-owned generation companies
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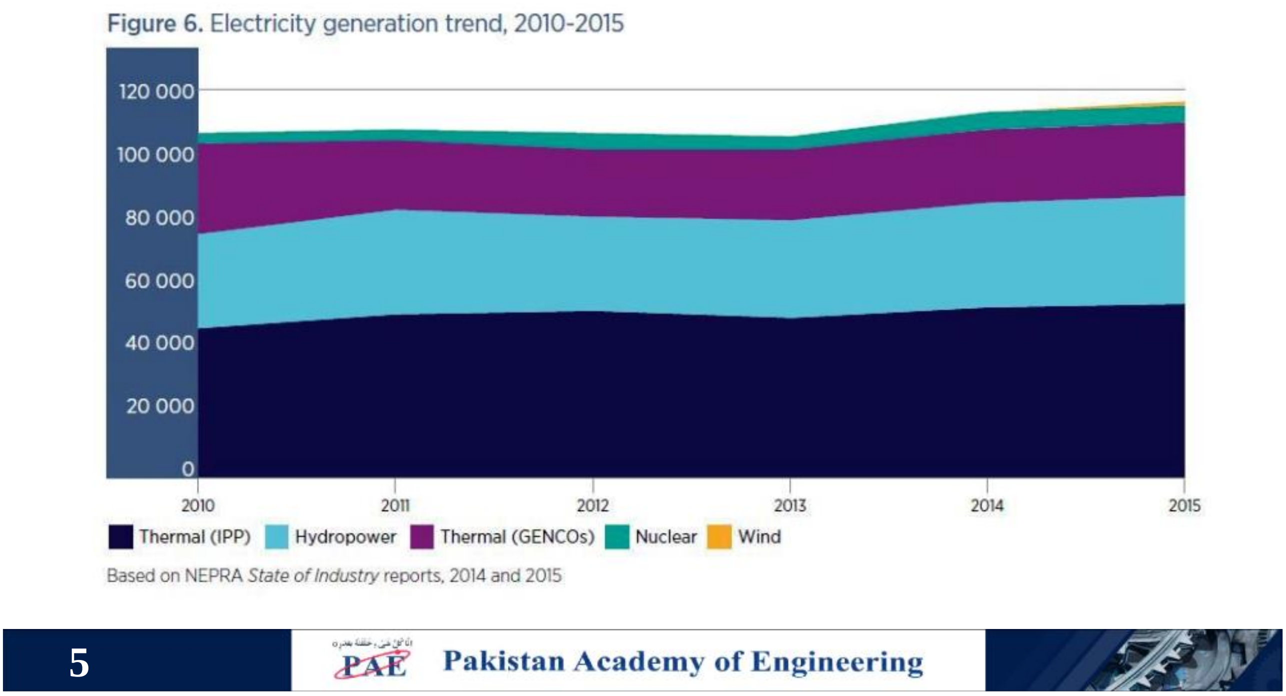
Figure 6. Electricity generation trend, 2010-2015
120 000
100 000
80 000
60 000
40 000
20 000
0
2010
2011
2012
2013
2014
2015
Thermal (IPP)
Hydropower
Thermal (GENCOs)
Nuclear
Wind
Based on NEPRA State of Industry reports, 2014 and 2015
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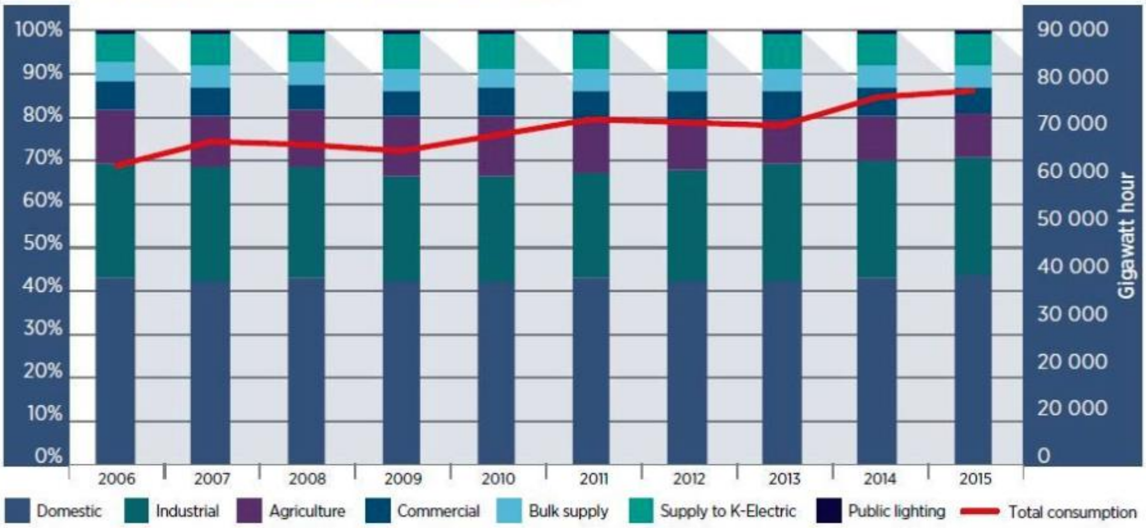
Figure 7. Power consumption by sector, 2006-2015



Based on NEPRA *State of Industry* reports, 2014 and 2015

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Table 2. Electricity demand and supply projections (NTDC and K-Electric)

FY	Capacity addition per year (MW)	Total installed capacity (MW)	NTDC peak demand (MW)
2017	2 585	27 959	27 175
2018	8 422	36 381	28 668
2019	1 656	38 037	30 138
2020	5 422	43 459	31 619

Source: NEPRA (2016a), *State of Industry Report 2015*

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3.2. Keynote Presentation: "Role of Nuclear Power in Pakistan with Emphasis on Small Modular Reactors (SMRs)"

by Mr. Saeed Alam Siddiqui,
Member Chairman's Advisory Council, PAEC
(Delegate of Mr. Muhammad Naeem, Chairman PAEC)

ROLE OF NUCLEAR POWER IN PAKISTAN WITH EMPHASIS ON SMALL MODULAR REACTORS (SMRs)

Saeed Alam Siddiqi
Member Chairman's Advisory Council
Pakistan Atomic Energy Commission
28 April, 2018

Significance of Nuclear Power

- Base Load Electricity Source
- Enhances Energy Security
- Reliable (High Availability/Capacity Factors)
- Clean (Environment Friendly)
- Cheap Source of Energy

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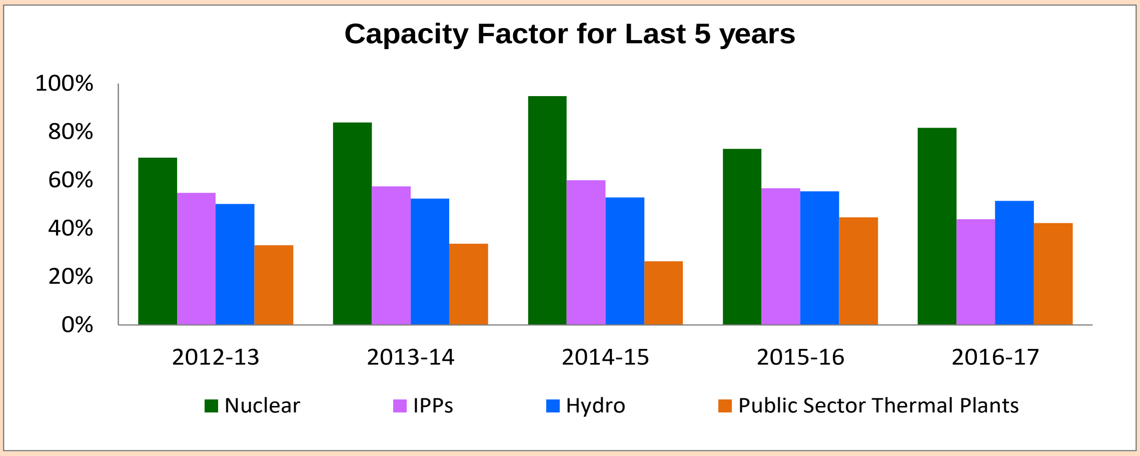
Reliable Base Load Electricity Source

- **Based on NEPRA statistics, it is evident that if all power plants in Pakistan would have operated, or could operate, at the combined average capacity factors of nuclear power plants, there would have been, practically, no load shedding in the country.**



Sources: a) NEPRA State of Industry Report 2016 (published in 2017)
b) 42nd Power System Statistics 2016-17, NTDC

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Enhanced Energy Security

- **Nuclear power helps enhancing energy security.**
  - **Substitute imported fuels**
  - **A 1000 MW nuclear power plant requires 240 tonnes of Uranium fuel worth Rs. 5 B avoiding annually:**
    - **2.43 million tons of Coal worth Rs. 40 B**
    - **1.48 million tonnes of Furnace Oil worth Rs. 82 B**
    - **47 billion cubic feet of Natural Gas worth Rs. 79 B**

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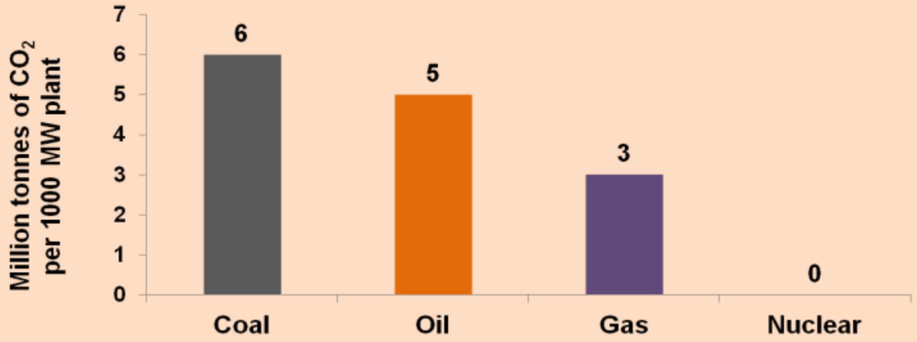
Clean Source of Energy

- Nuclear power plants do not emit harmful pollutants including Greenhouse Gases responsible for climate change.
- A 1000 MW coal, oil and gas fired power plant annually emits, on average, 6, 5 and 3 million tons of CO_2, respectively.



Source: Comparison of Life Cycle Greenhouse Gas Emissions of various electricity generation sources, WNA report, July 2011

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Clean Source of Energy (Contd.)

- International community has agreed in Paris to hold the increase in average global temperature to well below 2°C above pre-industrial levels.
- Pakistan is a signatory to this agreement.
- To meet Paris target, nuclear power capacity will have to go up 2.46 times of current global capacity 392 GW, by 2050 (964 GW).
- Currently, worldwide, nuclear power is avoiding nearly 2 billion tons of carbon dioxide per year.

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Clean Source of Energy (Contd.)

Nuclear power reduces environmental costs

Health Impacts and Costs from Coal Power Generation in Europe

Health Impact	Euro million (2009)
Chronic mortality (premature deaths)	37,954
Chronic mortality (life years lost)	10,596
Chronic bronchitis	1,785
Lower respiratory symptoms	1,201

Source: The Unpaid Health Bill, How coal power plants make us sick, Health and Environment Alliance (HEAL), www.env-health.org, 2013.

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Clean Source of Energy (Contd.)

Nuclear power reduces environmental costs

Acid Rains (SO_2 and NO_x responsible) costs in China in 2003

Crop damage	Yuan 30 billion (US$ 3.9 billion)
Material damage	Yuan 7 billion (US$ 0.9 billion)

Source: Cost of Pollution in China, the World Bank, State Environmental Protection Administration, P. R. China, February 2007.

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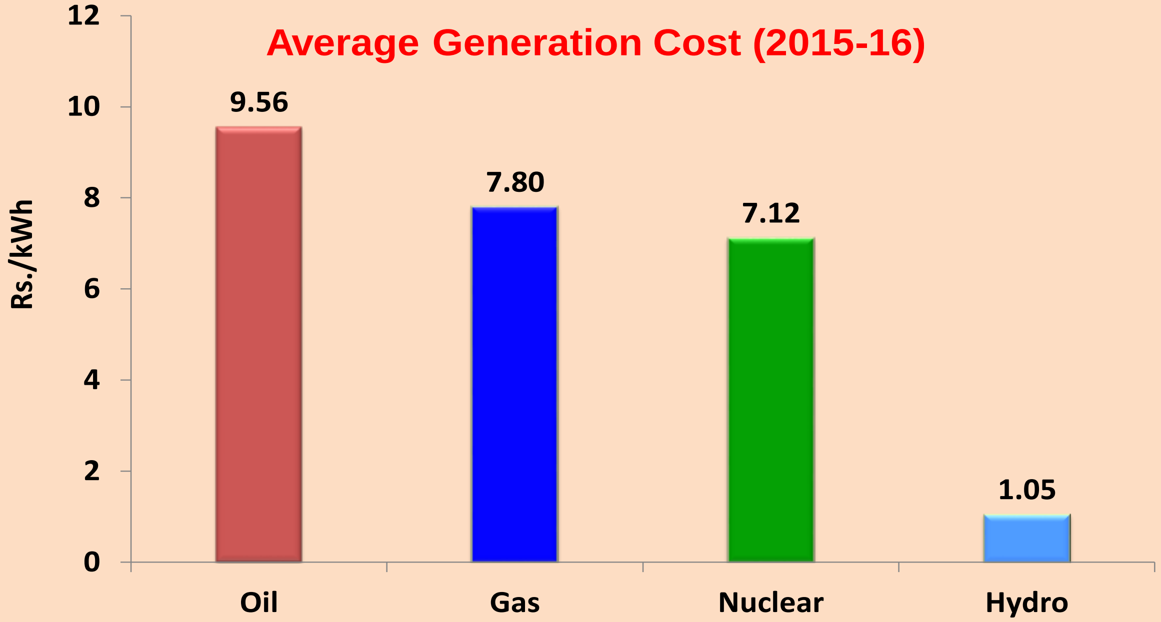
Cheap Source of Energy



Source: NEPRA State of Industry Report 2016 (published in 2017) and PAEC data

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Nuclear power: Global Picture

- Countries using nuclear power : 31
- Units in operation : 450
  - Total net installed capacity : 394 GW
- Electricity generation in 2016 : 2616 TWh (10.5 % of total)
- Units under construction : 55
  - Total capacity : 56 GW
- Units under const. in China : 18
  - Total capacity : 19 GW

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Operational Nuclear Power Plants in Pakistan

	KANUPP 	C-1 	C-2 	C-3 	C-4 
Capacity (Gross)	137/100 MW	325 MW	330 MW	340 MW	340 MW
Grid Connection	04-10-1972	13-06-2000	14-03-2011	15-10-2016	25-06-2017
Commercial Operation	07-12-1972	15-09-2000	18-05-2011	06-12-2016	26-09-2017
Life Time Capacity Factor	32%	75%	82%	93%	65%
Current Capacity Factor	48% (2017)	97% (Cycle-12)	100% (Cycle-5)	93% (Cycle-1)	65% (Cycle-1)
Highest Continuous Operation Record	167 Days (2016-2017)	280 Days (24-02-2017)	302 Days (20-11-2016)	113 Days (17-05-2017)	55 Days (09-03-2018)

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Nuclear Power Plants Under Construction in Pakistan

	K-2 	K-3 
Capacity (Gross)	1100 MW	1100 MW
Groundbreaking	26-11-2013	26-11-2013
First Concrete Date (FCD)	20-08-2015	31-05-2016
Containment Dome Placement	13-10-2017	-
Commercial Operation	2020	2021

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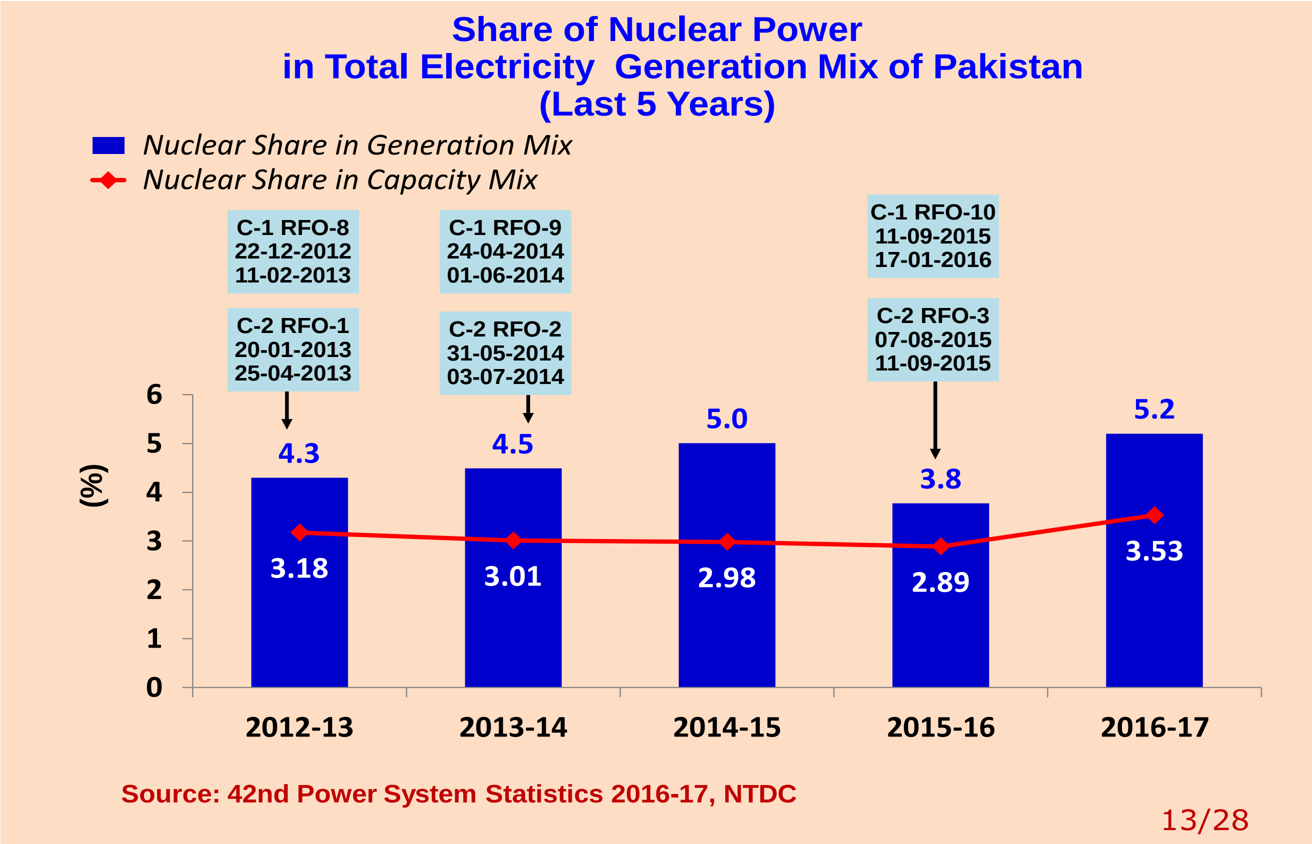
Share of Nuclear Power
in Total Electricity Generation Mix of Pakistan
(Last 5 Years)
Nuclear Share in Generation Mix
Nuclear Share in Capacity Mix
C-1 RFO-8
22-12-2012
11-02-2013
C-2 RFO-1
20-01-2013
25-04-2013
C-1 RFO-9
24-04-2014
01-06-2014
C-2 RFO-2
31-05-2014
03-07-2014
C-1 RFO-10
11-09-2015
17-01-2016
C-2 RFO-3
07-08-2015
11-09-2015
(%)
6
5
4
3
2
1
0
4.3
4.5
5.0
3.8
5.2
3.18
3.01
2.98
2.89
3.53
2012-13
2013-14
2014-15
2015-16
2016-17
Source: 42nd Power System Statistics 2016-17, NTDC
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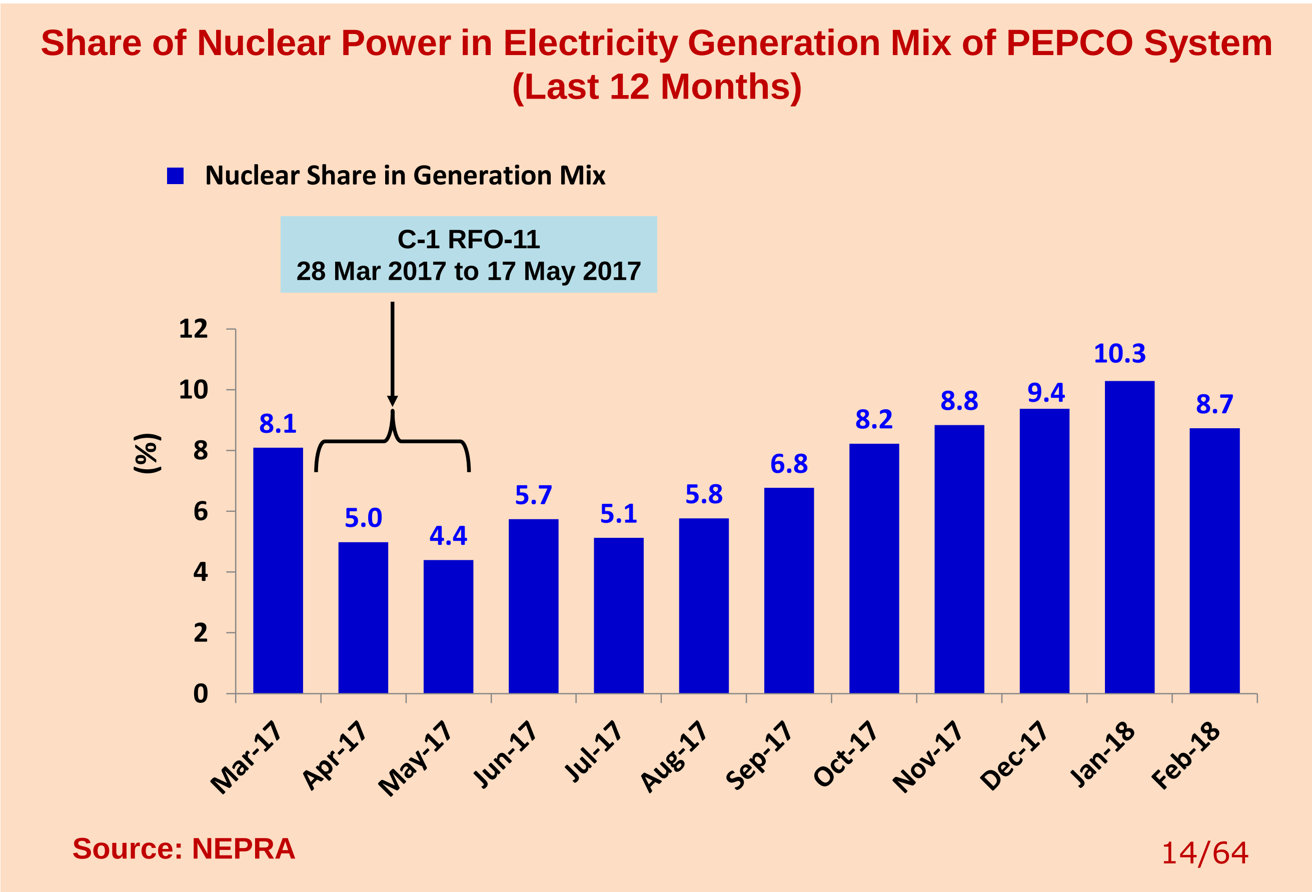
Share of Nuclear Power in Electricity Generation Mix of PEPCO System
(Last 12 Months)
Nuclear Share in Generation Mix
C-1 RFO-11
28 Mar 2017 to 17 May 2017
(%)
12
10
8
6
4
2
0
8.1
5.0
4.4
5.7
5.1
5.8
6.8
8.2
8.8
9.4
10.3
8.7
Mar-17
Apr-17
May-17
Jun-17
Jul-17
Aug-17
Sep-17
Oct-17
Nov-17
Dec-17
Jan-18
Feb-18
Source: NEPRA
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Targets in Energy Security Plan of GoP 2030

MW

	Gas	Hydro	Coal	Renewable	Nuclear	Oil	Total	Cumulative
2005	5,940	6,460	160	180	400	6,400	19,540	
Projected additions								
2010	4,860	1,260	900	700	-	160	7,880	27,420
2015	7,550	7,570	3,000	800	900	300	20,120	47,540
2020	12,560	4,700	4,200	1,470	1,500	300	24,730	72,270
2025	22,490	5,600	5,400	2,700	2,000	300	39,490	110,760
2030	30,360	7,070	6,250	3,850	4,000	300	51,830	162,590
Total	83,760	32,660	19,910	9,700	8,800	7,760	162,590	

Source: Medium -Term Development Framework (2005-2010), Planning Commission, Govt. of Pakistan, May 2005.

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Nuclear Power: Vision 2050

- In 2011, Nuclear Power Vision 2050 was approved by the National Command Authority. It set forth a target of 40,000 MW of nuclear power capacity by 2050.
- Vision 2050 was endorsed by the Prime Minister on 26 November, 2013 at the Groundbreaking ceremony of K-2/K-3.

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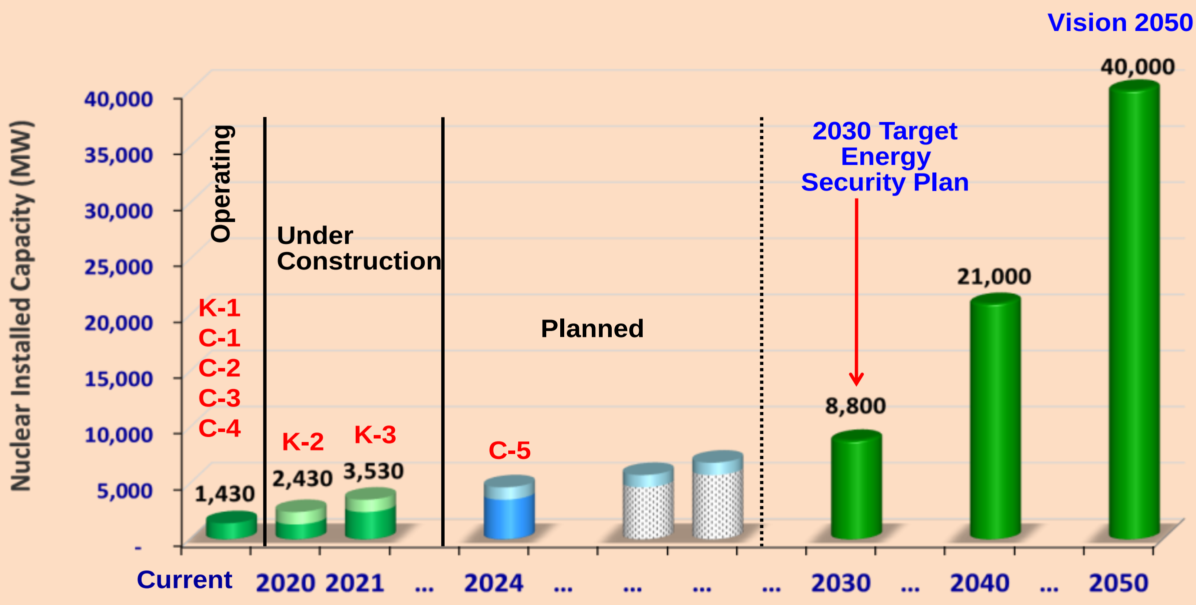
Nuclear Power Vision of 40,000 by 2050



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Prospects of Small Modular Reactors (SMRs)

- To fill the gap between supply and demand, rapid addition of cheap and clean electrical capacity to national grid is urgently required.
- PAEC is implenting its plan for generation of 8800 MW from nuclear by 2030 using larger units (1000 MW) due to economy of scale. However, addition of newer generation small modular reactors (Gen. III+ and Gen. IV), with shorter construction times and moderate financial commitments is also a promising option in the coming years.
- Far-flung areas of Pakistan, away from national grid, require small decentralized power plants. Modular design of SMRs could allow customized NPPs for such regions.
- Pakistan has long coastal area with severe shortage of potable water specially in metropolitan of Karachi and Gwadar port area. Desalination using nuclear energy from SMR could be useful in these areas.

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Introduction to Small Modular Reactors (SMRs)

- **SMRs are newer generation reactors (Gen. III+ and Gen. IV) designed to generate electric power up to 300 MW with shop fabricated components and systems and transported as modules to the sites for installation.**
- **Most of the SMR designs adopt advanced safety features and are deployable either as a single or multi-unit plant.**
- **SMRs are under development for all principal reactor lines, i.e.**
  - **Water cooled reactors**
  - **High temperature gas cooled reactors**
  - **Liquid-metal, sodium and gas-cooled reactors with fast neutron spectrum**
  - **Molten salt reactors**

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Driving Forces

- **The key driving forces of SMR development are :**
  - **Fulfilling the need for prompt power generation source for a wide range of users and applications**
  - **Replacing ageing fossil fuel fired power units**
  - **Inherent safety features (passive systems, underground containment)**
  - **Offering better economic affordability**
  - **Shorter construction time**
  - **Smaller Emergency Planning Zone**
  - **Deployable near load centres/remote areas**

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Specific Characteristics

- **Many SMRs are envisioned for energy markets where large reactors are not viable.**
- **SMRs can be deployed incrementally resulting in a moderate financial commitment for countries or regions with smaller electricity grids.**
- **SMRs show significant cost reductions through modularization and factory construction with short construction schedule.**
- **SMR designs and sizes are better suited for partial or dedicated use in non-electrical applications such as providing heat for industrial processes, hydrogen production, district heating or sea-water desalination.**

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Safety Features of SMRs

Most of the water cooled SMRs employ passive safety systems based on natural circulation which have following advantages:

- Require no AC power to actuate/operate Engineered Safety Features
- Only natural circulation forces needed to safely cool the reactor core, shutdown the reactor and remove decay heat out of containment
- Fewer number of plant systems and components reduce plant construction and O&M cost
- Provide about 7 days of reactor cooling without AC power or operator action

The underground containment structure of SMRs provide:

- Better protection against the impacts of severe weather
- Better seismic strength
- Enhanced protection against fission product release
- Improved physical security, aircraft impacts and conventional warfare

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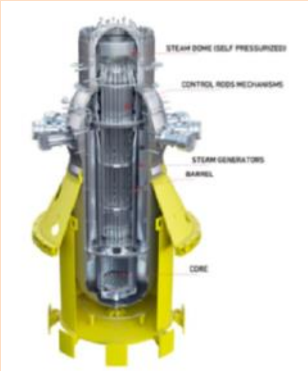
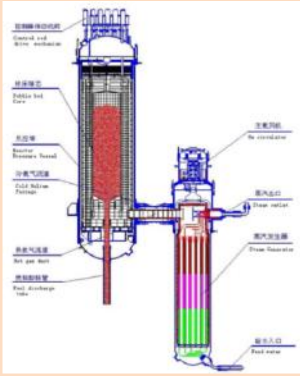
SMRs under construction

CAREM, Argentina
30 MWe,
IPWR*
Target Commissioning
Dec. 2018



KLT-40S, Russia
35 MWe, Compact Loop PWR, Ship Borne
Target Commissioning
Dec. 2019

HTR-PM , China
250 MWe, Modular Pebble Bed High Temp Gas cooled reactor
Target Commissioning
Dec. 2018



* Integrated Pressurized Water Reactor

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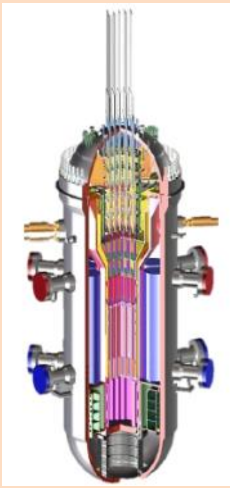
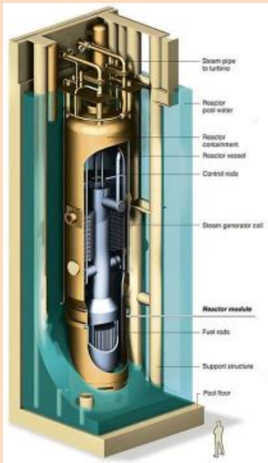
Near Term Deployable SMRs

ACP-100, China
100 MWe
IPWR*
Basic Design complete

SMART , S. Korea
100 MWe
IPWR*
Standard design approval granted



NuScale , USA
50 MWe
IPWR*
Design certification process underway



* Integrated Pressurized Water Reactor

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Technical Issues

- **Though significant advancements have been made in various SMR technologies in recent years, some technical issues still attract considerable attention in the industry. These include :**
  - **Control room staffing for multi-module SMR plants**
  - **Determination of radioactive material inventory (source term) for multi-module SMR plants with regard to emergency planning zone**
  - **Developing new codes and standards, and also load-following operability aspects.**

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SMR Capital Cost

Serial No.	Design	Country	Total Plant Output (MW)	Capital Cost ($, millions)	Capital Cost ($/KW)
1	NuScale	U.S	12 x 45	2,500	4,630
2	SMART	S. Korea	100	500	5,000
3	CAREM	Argentina	25	100	4,000
4	KLT-40S	Russia	70	263	3,757
5	ACP-100	China	2 x 100	800	4,000

Source: Data compiled from public information and UxC estimates for Nth of a kind Projects (4th Annual Platts SMR Conference, May 29, 2013)

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Future Outlook

- **PAEC is pursuing R&D program in the field of SMR and development of required Infra-structure.**
- **PAEC has been involved in the design of nuclear power plants and possesses expertise in NPP operation and maintenance.**
- **PAEC has also developed facilities for manufacturing of some NPP components in Pakistan.**
- **International collaboration at forums like IAEA is also underway.**
- **PAEC is well on its way to adopt the SMR technology as it is matured and becomes commercially viable.**

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Thank You

3.3. Presentation:
"The Lessons Learned in the Development of Nuclear Power Plants in the USA"

by Engr. Mohammad Irshad, P.E., USA

About the Author

Mohammad Irshad, PE
Consultant Nuclear Power Plants, Lincoln, California, USA

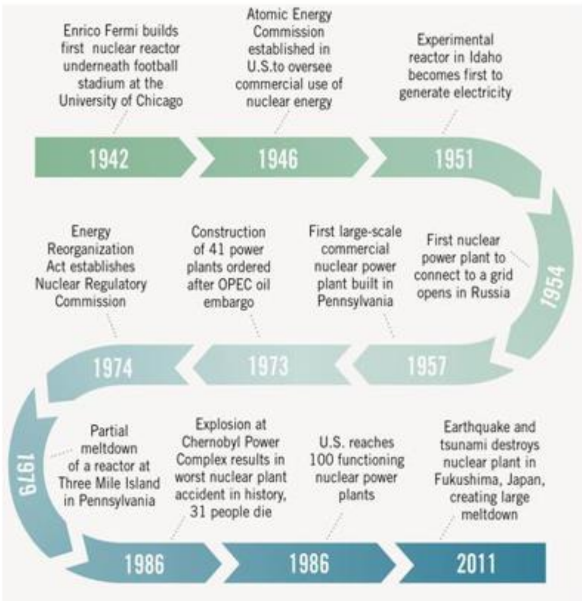
1969 graduate of NED Engineering College, Karachi and holds a Master's degree in Mechanical Engineering from Illinois Institute of Technology, Chicago. He is Registered Professional Engineer in state of Illinois and California.
Worked on design and construction support of Nuclear Power Plants in Illinois, California, Texas and Tennessee. He was part of Plant Design group for Nuclear Waste Treatment Plant (WTP), Hanford, Washington.
He held positions from Stress Analyst to Project Manager and currently retired as Consultant living in Lincoln, California.
Based on working experience in US nuclear industry these slides present the lessons learned that can helpful to avoid pitfall in developing a nuclear program.

The US Utilities background

- The US the industrial Power plants are built, owned and operated by electrical utilities companies.
- Utilities companies are private enterprises. The business model uses funds by investors to build power plants and distribute the power at profit. The profit is used to pay dividends to stockholders.
- The utilities management shall make decision carefully understanding the risks and rewards. A bad decision can lead to financial disaster and bankruptcy.
- Since the utilities have no expertise in building power plants they hire engineering and construction companies to build and commission the plants.
- Nuclear Power Plants are licensed by Nuclear Regulatory Commission (NRC) before operation.

The US History of Nuclear Power

- The USA is an undisputable leader in developing and utilizing the nuclear power plants for commercial use.
- The nuclear industry saw sharp rise in 1973 "oil crisis," that threw US energy policy and planning into turmoil. Overnight, oil prices quadrupled, and coal—until then the mainstay of electricity generation—also rose in price. Under Project Independence Program, to increase the exploitation of domestic energy supplies called for the building of 1,000 large nuclear reactors by the year 2000.
- Only 253 nuclear power reactors ordered in the United States from 1953 to 2008.
    - 48 percent were canceled
    - 11 percent were prematurely shut down
    - 14 percent experienced at least a one-year-or-more outage
    - and only 27 percent are operating without having a year-plus outage.



Collapse of Nuclear Power Industry in the US

- ❑ Most reactors began construction by 1974
- ❑ Three Mile Island accident in 1979 and changed economics
- ❑ More than 100 orders for nuclear power reactors, many already under construction, were canceled in the late 1970s and 1980s
- ❑ Some of the utilities companies went bankrupt
- ❑ Up until 2013, there had also been no ground-breaking on new nuclear reactors at existing power plants since 1977
- ❑ In 2012, the NRC approved construction of four new reactors at existing nuclear plants
  - Construction of the Virgil C. Summer Nuclear Generating Station Units 2 and 3 began on March 9, 2013 but was abandoned on July 31, 2017
  - On March 12, 2013 construction began on the Vogtle Electric Generating Plant Units 3 and 4, but has been stalled as the reactor supplier Westinghouse filed for bankruptcy protection on March 29, 2017.
  - On October 19, 2016 TVA's Unit-2 reactor at the Watts Bar Nuclear Generating Station became the first US reactor to enter commercial operation since 1996. The plant was 80 % complete when it was abandoned in 1985.

THE COLLAPSE OF NUCLEAR REACTOR ORDERS
1966 to 1978

Lessons learned

- ❑ Problems and eventual collapse of nuclear industry offers interesting lessons to be learned
- ❑ These lessons can be used in the future planning of any nuclear power programs to avoid pitfalls

Disclaimer:

- *The author is not anti nuclear but pro nuclear*
- *Does not belong to any anti or pro nuclear group*
- *Purpose of this presentation is to educate the audience the reasons that lead to collapse of nuclear industry in the US as lessons learned by his working experience in the industry*

Plant Sizes

- The average generating capacity of coal plants in the United States is 547 megawatts
- The largest single nuclear reactor in the United States is the Grand Gulf Nuclear Generating Station, with 1,500 megawatts in generating capacity

- Larger the size of plant
  - Higher the cost (design, construction and operation)
  - Less flexibility in managing the output of plant

Custom or non standard design

Since the technology was not sufficiently mature to employ design of well established quality and safety practices. Every power plant currently operating in the United States is a unique and hand-detailed. Customized or non standard plant design resulted in

- Increased cost
- Delayed delivery of reactors
- Lengthy licensing procedures
- Components, personnel and operating procedures became non interchangeable
- Spare and supply chain became unreliable
- Learn as go approach based on cost plus contracts

Only small and standard plants could improve efficiency and safety of plants while cutting costs.
These power generators could be built in 3-4 years, compared to 7-10 years or more for larger reactors.
Could be, in principle, built in factories and then delivered to the site in larger pieces.

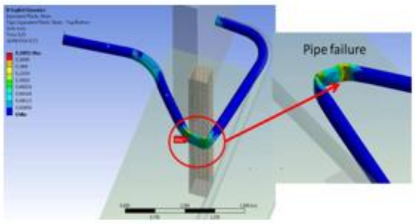
Note: Chinese were first to learn the lesson by turning out something more like prefab units—cheap to make, easy to modify, and quick to go up. Not only are China's reactors using a standardized design with some modular parts, but the entire construction process is performed by a dedicated crew that travels from reactor site to reactor site.

Overdesign

- ❑ Initial design plant design was based on ASME Boiler and Pressure Vessel Code (B&PVC) ASME B31.1
- ❑ In 1963 Section III of ASME Boiler and Pressure Vessel Code was issued specifically for Nuclear Power Plant Design. Section III impacted the design and construction of plants. An unprecedented level of analysis and testing requirements were implemented. Result was not just delay in design but significant rise in construction cost.
- ❑ Three Mile Island accident was a significant turning point in the global development of nuclear power plants. Following the accident NRC issued number of regulatory guides impacting design, construction and operation of plants.
- ❑ Additional quality assurance became a mandatory requirement.
- ❑ NRC required additional time to review permits for construction and delayed issuance of operating licenses
- ❑ The industry faced with scare supply of critical resources to deal with technical and operational problems.

Most of these requirements resulted in overdesigned plant for the reason of safety.

A good example is whip restraint design inside containment.



Pipe Whip Restraint design

Economics of Nuclear Power Plants

An industry needs to be more efficient and reduce costs over time to survive in competitive environment

- ❑ While it's expensive to develop any kind of energy infrastructure, the cost of nuclear energy has not fallen over time.
- ❑ Nuclear power and solar photovoltaics (PV) both had their first recorded prices in 1956. Since then, the cost of nuclear power has gone up by a factor of three, and the cost of PV has dropped by a factor of 2,500.
- ❑ This explains why it's difficult for electric utilities to build new plants, even with some new financial incentives and regulatory changes that have streamlined the licensing process recently.
- ❑ In 2014, the Energy Information Administration estimated that building a nuclear power plant could cost more than $12 billion, and it would be at least six years before it could start producing power.
- ❑ One of the main factors causing the industry's economic problems is the country's large, cheap supply of natural gas. The supply became available due to widespread fracking operations.
- ❑ There is much lower demand in the U.S. for electricity than ever before. This came about after many improvements in energy efficiency and success with conservation efforts.

China appears to be lowering the cost of nuclear development, but it's hard to say whether that appearance reflects reality. The Chinese nuclear industry is not a free market. The steel for their reactors comes from state-owned mills and is processed in state-owned machining operations. There are price controls and forced relationships at every level.

Cost Overrun

- The original cost estimates at order for plant were between $500 million and $1 billion
- The final costs escalate up to 10 times that amount, over the course of construction
- The reasons were
  - Unreasonable regulations by the Nuclear Regulatory Commission,
  - The stretch-out of schedules over "environmental and safety" concerns.

Note that GE and other U.S. firms currently build 1,000 MW and larger nuclear units in Japan, Korea, and Taiwan in 4 to 5 years.

PROJECTED VS. ACTUAL COST OF SELECTED NUCLEAR POWER PLANTS
(in billions of dollars)

Unit	Megawatts	Initial cost estimate	Actual cost
Millstone III (Massachusetts and Connecticut)	1,150	.400	3.82
Limerick 1 (Pennsylvania)	1,055	.344	3.80
Wolf Creek (Kansas)	1,055	1.03	2.93
Susquehanna 1 (Pennsylvania)	1,050	.665	2.05
Susquehanna II (Pennsylvania)	1,050	.720	2.05

Source: Public Utility Commissions in the respective states

Waste disposal issues

- Nuclear Power Plants were designed and built without a long-term solution to store nuclear waste. Temporary on-site spent fuel pools were built.
- As plants continue to age, many on-site spent fuel pools have come to near capacity, prompting creation of dry cask storage facilities as well.
- There are some 65,000 tons of nuclear waste now in temporary storage throughout the U.S Since 1987, Yucca Mountain, in Nevada, had been the proposed site for the Yucca Mountain nuclear waste repository, but the project was shelved in 2009 following years of controversy and legal wrangling.
- At Maine Yankee, Connecticut Yankee and Rancho Seco Plants, reactors no longer operate, but the spent fuel remains in small concrete-and-steel silos that require maintenance and monitoring by a guard force.
- The presence of nuclear waste prevents re-use of the sites by industry.
- Nine states have "explicit moratoria on new nuclear power until a storage solution emerges.
- Given cost considerations and the risk of nuclear proliferation no adequate technology exist for permanent disposal of waste.
- There is a consensus on the advisability of storing nuclear waste in deep underground repositories, but no country in the world has yet opened such a site.
- Without a long-term solution to store nuclear waste, a nuclear renaissance in the U.S. remains unlikely.

Plant decommissioning

- The price of energy inputs and the environmental costs of every nuclear power plant continue long after the facility has finished generating its last useful electricity.
- Nuclear reactors facilities must be decommissioned, returning the facility and its parts to a safe enough level to be entrusted for other uses.
- After a cooling-off period that may last as long as a century, reactors must be dismantled and cut into small pieces to be packed in containers for final disposal. The process is expensive, time-consuming and dangerous for workers, hazardous to the natural environment, and presents new opportunities for human error, accidents or sabotage.
- The decommissioning process costs between US $300 million to $5.6 billion. Decommissioning at nuclear sites which have experienced a serious accident are the most expensive and time-consuming.
- New methods are required for decommissioning to minimize the usual high decommissioning costs.
- It is expected that by 2025 many of the reactors will have been shut down due to their age. It is projected that the coal and natural gas appears to be convenient solutions for the energy problem that is encountered in the US.

Public opposition to nuclear power

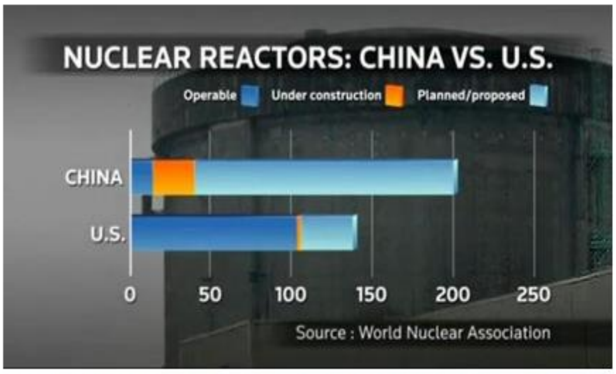
Nuclear energy was conceived in secrecy, born out of war, and first revealed to the world in horror.

- No matter how many proponents try to separate the peaceful use of nuclear power from the nuclear weapons the connection is firmly embedded in the mind of the US public for the opposition of nuclear power.
- Some sixty anti-nuclear power groups are operating, or have operated, in the United States. These include: Abalone Alliance, Clamshell Alliance, Greenpeace USA, Institute for Energy and Environmental Research, Musicians United for Safe Energy, Nuclear Control Institute, Nuclear Information and Resource Service, Public Citizen Energy Program, Shad Alliance, and the Sierra Club
- Many anti-nuclear protests in the United States captured national public attention during the 1970s and 1980s. These included Clamshell Alliance protests at Seabrook Station Nuclear Power Plant and the Abalone Alliance protests at Diablo Canyon Nuclear Power Plant, where thousands of protesters were arrested. Other large protests followed the 1979 Three Mile Island accident.
- Several US nuclear power plants closed well before their design lifetimes, due to successful campaigns by anti-nuclear activist groups. These include Rancho Seco in 1989 in California and Trojan in 1992 in Oregon. Humboldt Bay in California in 1976. Shoreham Nuclear Power Plant was completed but never operated commercially as an authorized Emergency Evacuation Plan could not be agreed on due the political climate after the Three Mile Island accident.
- Despite many technical studies which asserted that the probability of a severe nuclear accident was low American public is still very deeply distrustful and uneasy about nuclear power.

A Note China vs. US

Public opposition to nuclear power matters

China currently has the fastest growing civil nuclear program in the world, with 34 reactors online and 20 under construction.



There is growing advocacy in China for an expanded role for public input in planning these projects – currently decisions at the planning stages are made with little input from residents

Lianyungang's protests demonstrates that Public opinion matters a great deal in China. The last thing the Chinese government wants is people protesting on the streets.

Summary and conclusion

- ✓ Plant size: Bigger is not always better.
- ✓ Standardize the design. Use prefabricate module approach.
- ✓ Over Design: Make it safe but not the safest ever built.
- ✓ Economics of Nuclear Power Plants: Be competitive to be justified.
- ✓ Cost Over Run: Understand, plan and control the cost.
- ✓ Waste Disposal Issues: Plan for spent fuel storage and eventual disposal.
- ✓ Plant decommissioning: Think ahead.
- ✓ Public opposition to nuclear power: Educate public in safety of nuclear power program.


Thank you

3.4. Presentation:
"Global Development of SMRs - Prospects & Challenges"

by Mr. Hidayatullah, Manager SMR Technology, PAEC

10th Symposium on Prospects of Mini Nuclear Power Plants in Pakistan
28th April, 2018, Pakistan Academy of Engineering, Karachi

Global Development of SMRs – Prospects and Challenges

Hidayatullah
Manager SMR Technology
Pakistan Atomic Energy Commission

Layout

- Countries with SMR Designs
- Power Range of SMRs
- SMRs for all Principal Reactor Lines
- Examples of SMR Designs
- Salient Design Characteristics
- Key Expected Advantages
- Prospects of SMR Designs
- Challenges of SMR Designs
- Challenges in SMR Deployment
- Answers Needed Prior to Deployment

2

Countries with SMR Designs

ARGENTINA
- CAREM

CANADA
- LEADIR-PS
- IMSR

CHINA

HTR-PM	CAP150/200
ACP100	ACPR50S

DENMARK
- MSTW

FRANCE
- FLEXBLUE

INDIA
- AHWR-300

JAPAN

4S	IMR
GTHTR300	FUJI
DMS	

REPUBLIC OF KOREA
- SMART

RUSSIAN FEDERATION

KLT-40S	SHELF	ELENA	MHR-T
RITM-200	UNITHERM	RUTA-70	SVBR-100
ABV-6E	KARAT-100	GT-MHR	BREST-OD-300
VBER-300	KARAT-45	MHR-100	

SOUTH AFRICA

PBMR-400	HTMR-100 SMR

UNITED KINGDOM
- Stable Salt Reactor

UNITED STATES OF AMERICA

NuScale	SC-HTGR	LFTR
mPower	Xe-100	SmAHTR
W-SMR	EM²	Mk1 PB-FHR
SMR-160	G4M	

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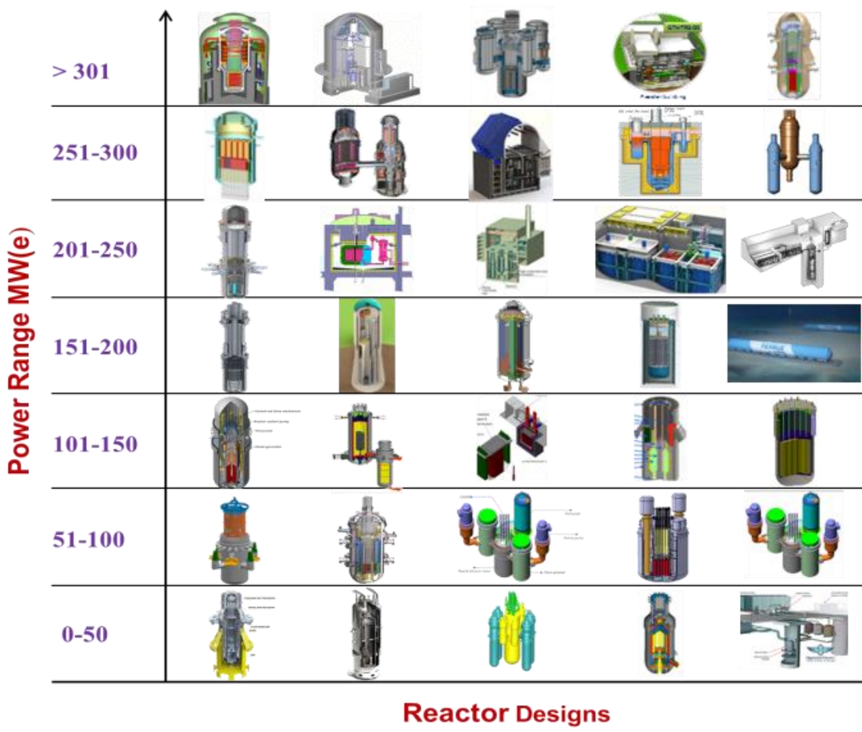
Power Range of SMRs



Power Range MW(e)	Reactor Designs
> 301	IMR, AHWR-300, VBER-300, GTHTR300, IRIS
251-300	DMS, GT-MHR, EM², BREST-OD-300, SC-HTGR
201-250	Westinghouse SMR, FUJI, MHR-T, ThorCon, LFTR
151-200	mPower, SMR-160, PBMR-400, IMSR, Flexblue
101-150	CAP150, HTR-PM, MSTW, Mk1 PB-FHR, SmAHTR
51-100	ACP100, SMART, MHR-100, SVBR100, ACPR50S
0-50	CAREM25, NuScale, KLT-40S, HTMR-100, G4M

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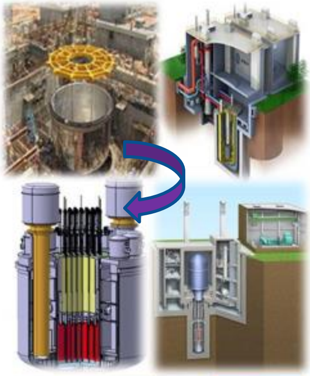
SMRs for all Principal Reactor Lines

Water cooled SMRs	Gas cooled SMRs	Liquid metal cooled SMRs
		
CAREM	HTR-PM	PFBR
SMART	GTHTR300	PRISM
ACP100	HTMR100	SVBR
NuScale	EM²	4S

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Water Cooled SMRs (Examples)

CAREM

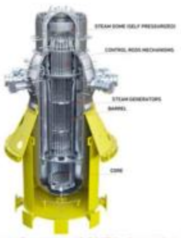


Image Courtesy of CNEA, Argentina

Under Construction

Integral PWR type SMR

Naturally circulation

- 30 MW(e) / 100 MW(th)
- Core Outlet Temp: 326°C
- Fuel Enrichment: 3.1% UO_2
- In-vessel control rod drive mechanisms
- Self-pressurized system
- Pressure suppression containment system
- Target commissioning: October 2018

SMART

Image Courtesy of KAERI, Korea

Licensed/Certified

Integral PWR type SMR

Forced circulation

- 100 MW(e) / 330 MW(th)
- Core Outlet Temp: 323°C
- Fuel Enrichment: 5% UO_2
- Multi-purpose application: electricity production, sea water desalination, district heating and process heat for industries
- Passive safety systems along with severe accident mitigation features
- Standard Design Approval: 4 July 2012

ACP100

Image Courtesy of CNNC, China

Basic Design

Integral PWR type SMR

Forced circulation

- 100 MW(e) / 310 MW(th)
- Core Outlet Temp: 323°C
- Fuel Enrichment: (2-4)% UO_2
- Underground nuclear island and spent fuel pool- enhanced protection against external hazards
- Containment vessel installed in water pool with fully passive safety facilities
- Modules per plant: (1 – 8)
- Undertaking IAEA's Generic Reactor Safety Review.

NuScale

Image Courtesy of NuScale Power, USA

Under development

Integral PWR type SMR

Naturally circulation

- 50 MW(e) / 160 MW(th) per module
- Core Outlet Temp: 302°C
- Fuel Enrichment: 4.95% UO_2
- Modules per plant: 12
- Containment vessel immersed in reactor pool that provide unlimited coping time
- Underground installment of containment vessel
- Submit Design Certification Review Application: 12/2016

6

6

High Temperature Gas Cooled SMRs (Examples)

HTR-PM

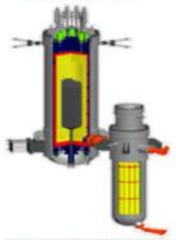


Image Courtesy of INET, China

Modular Pebble Bed High Temperature Gas Cooled Reactor

Helium/Graphite cooled

- 210 MW(e) / 500 MW(th)
- Core Outlet Temp: 750°C
- Fuel Enrichment: 8.5% UO_2 TRISO coated particle
- No. of fuel spheres: 420,000 /module
- Modules per plant: 2
- Advanced stage of construction- expected to be commissioned by 2018

GTHTR300

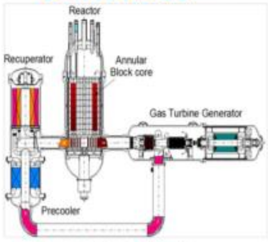


Image Courtesy of JAEA, Japan

Prismatic High Temperature Gas Cooled Reactor

Helium/Graphite cooled

- 100-300 MW(e) / 600 MW(th)
- Core Outlet Temp: 850-950°C
- Fuel Enrichment: 14 % UO_2 TRISO ceramic coated particle
- Fuel temperature limit: 1600°C
- Modules per plant: 4
- Inherent safety features
- Multi-purpose application: power generation, hydrogen production, process heat, steelmaking, desalination and district heating

HTMR100

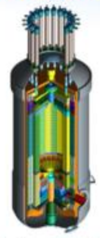


Image Courtesy of STL, South Africa

High temperature Gas Cooled Reactor

Helium cooled / graphite moderated

- 35 MW(e) / 100 MW(th) per module
- Core Outlet Temp: 750°C
- Fuel Enrichment: 15% Th/Pu, <10% U_{235} Th/LEU and Th/HEU
- Module per plant: (4-8) pack
- Number of Fuel units: ~150,000 pebbles
- Better load following capability and flexibility in multi-module configuration

EM²

Image Courtesy of General Atomics, USA

High Temperature Gas Cooled Fast Reactor

Helium cooled

- 240 MW(e) and 500 MW(th)
- Refuelling cycle: 30 years
- Core Outlet Temp: 850°C
- Fuel enrichment: 1% U_{235} - 1% Pu, MA coated particle
- Efficiency: 48%
- Fully enclosed in an underground containment
- Utilization of spent fuel
- Simplified power conversion system and 30% reduction in material requirements than that of current NPPs

7

Other Generation IV SMRs (Examples)

PRISM

Image Courtesy of GE Hitachi, USA

Power Reactor Innovative Small Modular

Liquid Sodium-cooled Fast Breeder Reactor

- 311 MW(e) / 840 MW(th)
- Core Outlet Temp: 485°C
- Fuel Enrichment: 26% Pu, 10% Zr
- Underground containment on seismic isolators
- For complete recycling of plutonium and spent nuclear fuel

4S

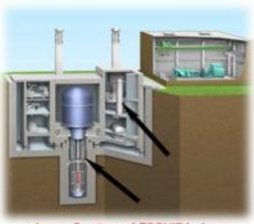


Image Courtesy of TOSHIBA, Japan

Super Safe Small Simple

Sodium-cooled Fast Reactor

- Fuel Cycle: 30 years
- 10 MW(e) / 30 MW(th)
- Core Outlet Temp: 510°C
- Fuel Enrichment < 20%
- Negative sodium void reactivity
- Hybrid of active and passive safety features
- Designed for remote locations and isolated islands, close to towns

SVBR100

Image Courtesy of AKME Engineering, Russia

Heavy Metal Liquid Cooled Fast Reactor 100 MW

Lead Bismuth Eutectic cooled Fast Reactor

- 101 MW(e) / 280 MW(th)
- Core Outlet Temp: 490°C
- Fuel Enrichment 16.5%
- Fuel Cycle: 8 years
- Hybrid of active and passive safety features
- Prototype nuclear cogeneration plant to be built in Dimitrovgrad, Ulyanovsk

IMSR

Image Courtesy of Terrestrial Energy, Canada

Integral Molten Salt Reactor

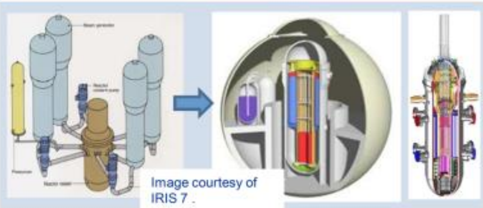
Molten Salt Reactor

- 80, 300 and 600 MW(th)
- Core Outlet Temp: 700°C
- Fuel Cycle: 7 years
- MSR-Burner: Efficient burner of LEU
- MSR-breeder: Thorium breeder
- Ideal system for consuming existing transuranic wastes (Long lived waste)
- Passive decay heat removal in situ without dump tanks

8

SALIENT DESIGN CHARACTERISTICS

Simplification by Modularization and System Integration



Multi-module Plant Layout Configuration

Underground construction for enhanced security and seismic

Enhanced Safety Performance through Passive System

- Enhanced severe accident features
- Passive containment cooling system
- Pressure suppression containment

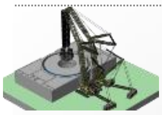
Image courtesy of BWX Technology, Inc.

9

KEY EXPECTED ADVANTAGES

Economic
- Lower Upfront capital cost
- Economy of serial production

Better Affordability



Modularization
- Multi-module
- Modular Construction

Shorter construction time

Flexible Application
- Remote regions
- Small grids

Wider range of Users

Smaller footprint
- Reduced Emergency planning zone

Site flexibility

Replacement for aging fossil-fired plants

Reduced CO_2 production

Potential Hybrid Energy System

Integration with Renewables

10

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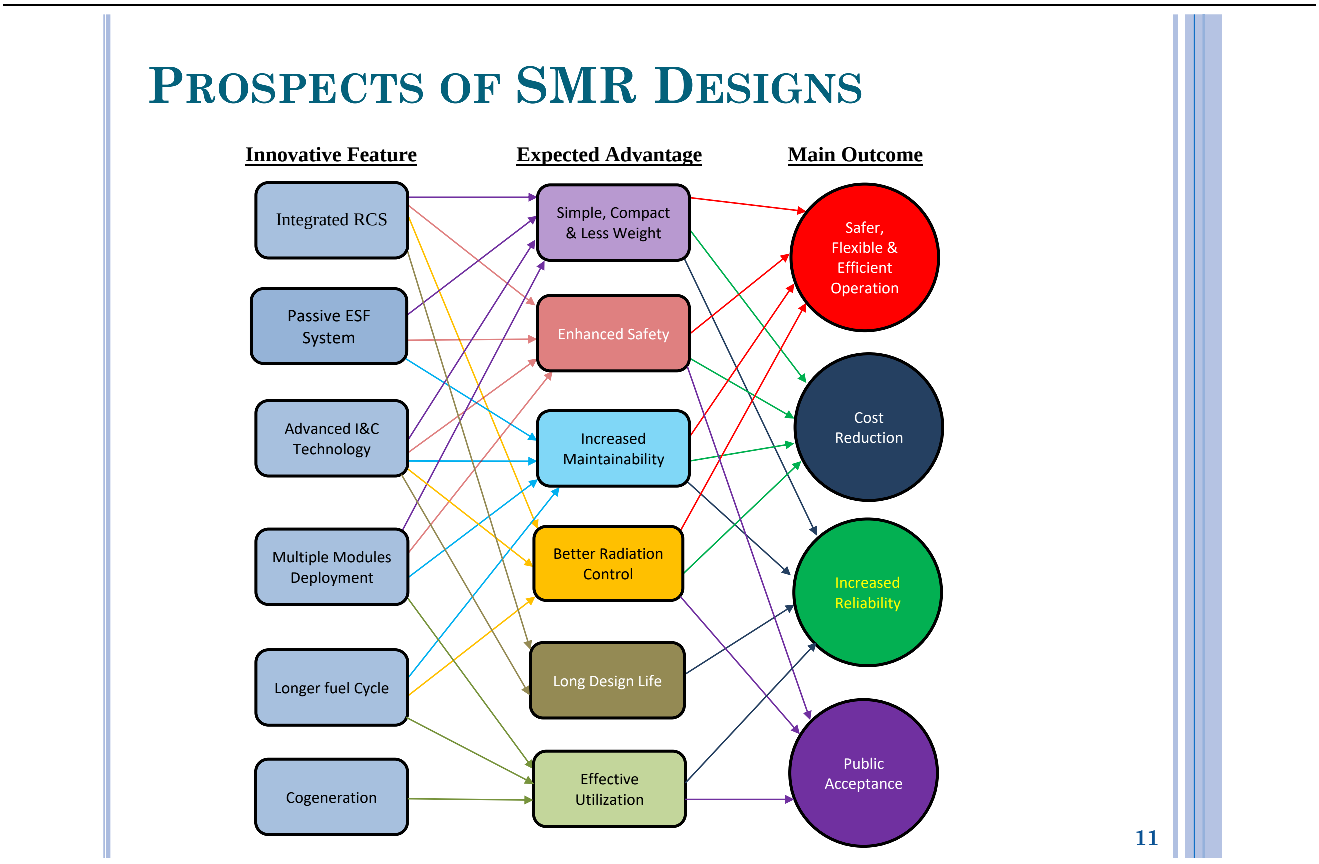
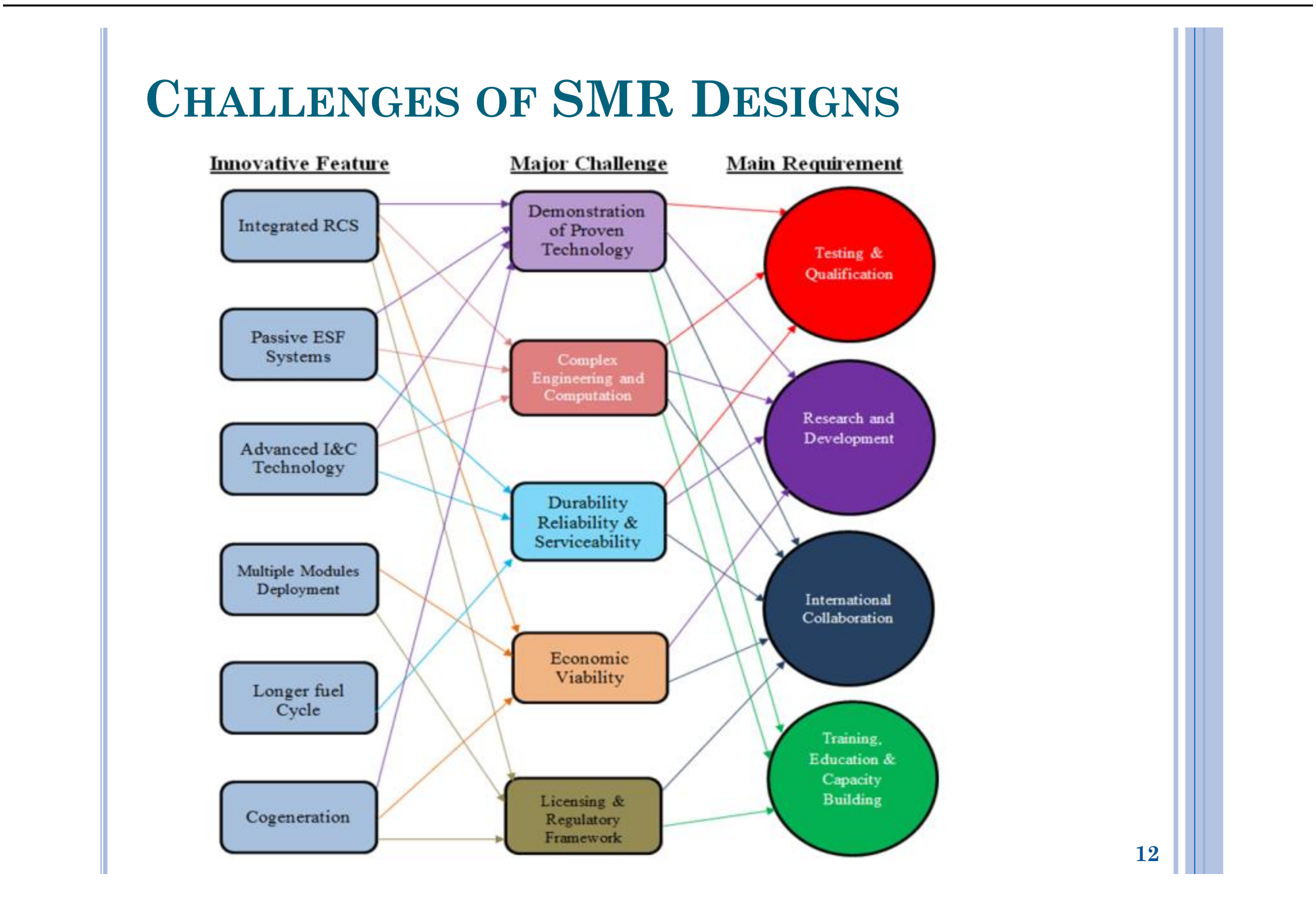

PROSPECTS OF SMR DESIGNS
Innovative Feature
Expected Advantage
Main Outcome
Integrated RCS
Passive ESF System
Advanced I&C Technology
Multiple Modules Deployment
Longer fuel Cycle
Cogeneration
Simple, Compact & Less Weight
Enhanced Safety
Increased Maintainability
Better Radiation Control
Long Design Life
Effective Utilization
Safer, Flexible & Efficient Operation
Cost Reduction
Increased Reliability
Public Acceptance
11


CHALLENGES OF SMR DESIGNS
Innovative Feature
Major Challenge
Main Requirement
Integrated RCS
Passive ESF Systems
Advanced I&C Technology
Multiple Modules Deployment
Longer fuel Cycle
Cogeneration
Demonstration of Proven Technology
Complex Engineering and Computation
Durability Reliability & Serviceability
Economic Viability
Licensing & Regulatory Framework
Testing & Qualification
Research and Development
International Collaboration
Training, Education & Capacity Building
12

CHALLENGES IN SMR DEPLOYMENT

- Design, licensing, and detailed engineering activities are at initial and planning stage
- Contain to some extent of 'first-of-a-kind' engineering systems and components, licensing and regulatory issues need to be addressed
- Newcomers are in favor of 'proven' technology and want SMR technologies to be first deployed in the country of origin to minimize licensing and performance risks
- Long-term reliability may be a major technological & material challenge
- Control room's designs, Human System Interfaces, I&C and the concept of operations are likely to be differed from conventional PWRs and are needed to be evaluated

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CHALLENGES IN SMR DEPLOYMENT (CONTD..)

- Plant staffing, training, qualifications and capacity building for embarking countries including regulatory authorities to cope with their licensing
- SMRs lose the benefit of economy of scale due to the lower electrical output per reactor; instead, they compensate with lower capital cost due to smaller and standardized components, relatively mass-produced components and systems and shorter construction time
- Regarding the challenge to enter the market, levelised cost of electricity (LCOE) for SMR might decrease in case of large-scale serial production so large initial order is necessary

Challenges: Detailed design & engineering, licensing & difficulties of modifying the existing regulatory and legal frameworks, multiple module deployment on the same site, the public accepts and demonstration of the proven technology of safe, secure economical nuclear power

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Answers Needed Prior to Deployment

- Whether multiple modules are to be considered one facility or individual facilities in the defence-in-depth?
- What is the maximum number of modules/ units to be permitted on one site and setting of its criteria?
- What control rooms staffing and safety implications and requirements of special considerations are needed for I&C?
- What type of training required for control personnel of multiple module plant?
- How the above challenges should be understood and resolved by the deploying organization?

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Thank You

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Pakistan Atomic Energy Commission
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Phone: +92-51-9321379

3.5. Presentation:
"Duplication of KANUPP Incorporating Current SMR Applications, Technology & SMR Features"

by Mr. Jamshed Azim Hashmi, Chief Engineer (Retd), PAEC, Chairman Emeritus, PNRA,
Mr. Javed Iqleem, Member Power (Retd), PAEC &
Mr. Waqar Murtaza Butt, Member Engineering (Retd), PAEC

SMALL MODULAR REACTORS (SMRs)

Duplication of KANUPP Incorporating Current SMR Applications, Technology & SMR Features

Jamshed Azim Hashmi
Chief Engineer (Retd), PAEC
Chairman Emeritus, PNRA
Javed Iqleem
Member Power (Retd), PAEC
Waqar Murtaza Butt
Member Engineering (Retd), PAEC

Definition of a SMR

Nuclear Reactors generally of size 300 Mwe equivalent or less. Designed with modular technology using module factory fabrication. Modular reactors allow for on less on-site construction designed for serial construction and collectively to comprise a large nuclear power plant.

- Fulfill Eisenhower's Atoms for Peace vision of nuclear power for an energy starved world. Currently only 30 countries have nuclear power plants (NPPs)

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Special Features that may be Incorporated in an SMR

- Increased containment efficiency
- Nuclear material security – proliferation resistance
- Can operate in weak grids – installation in isolated areas
- Multi-purpose electric power generator cum desalination
- Countries that desire a large eventual power output but want to start small and add module by module to comprise a large NPP
- Passive features – can be built without coolant pumps – natural convection circulation
- Seismic resistance
- Shorter construction time
- Comparatively lower capital cost
- Proliferation Resistance
- No On-Site Refueling
- Highly Effective Containment

3

Special Applications of an SMR

- In isolated areas, where there is absence of strong interconnected grid
- For electric generation cum seawater/ brackish water desalination
- For desalination alone
- This presentation proposes that duplicating KANUPP incorporating SMR features mentioned earlier and for use desalination in the arid Coast of Baluchistan
- Some production figures as follows:
  - Modified duplicated KANUPP SMR One 100 Mwe or ≅ 300 MWth => 45 Million gallons/day
    KANUPP SMR Two 70 Mwe or ≅ 200 MWth => 30 Million gallons/day
- Such an SMR can be used for both water supply for people, and also for trickle feed irrigation

NOTE: 1 m^3/ day = 220 gallons/day
150,000 m^3/ day = 33 Million gallons/day
120,000 m^3/ day = 26 Million gallons/day

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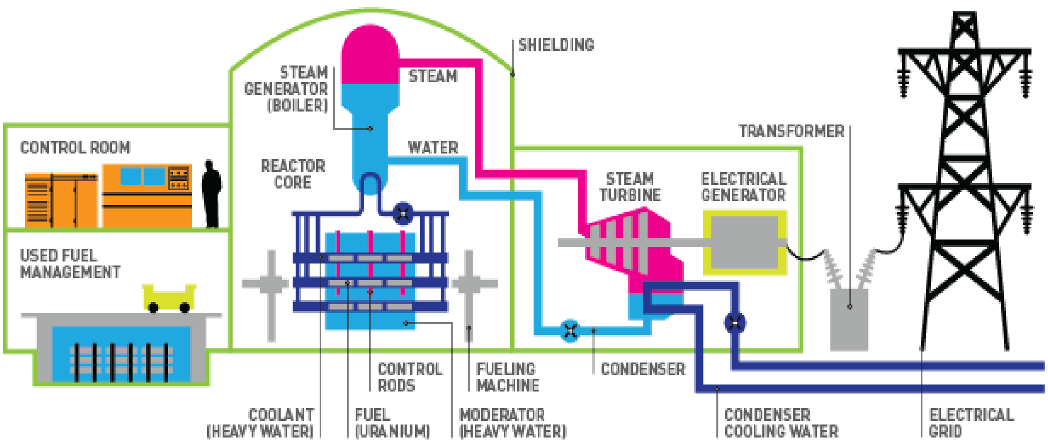
Early History & Present Status of Nuclear Reactors

Some Common Characteristics of Three (3) SMRs

Attributes	NuScale	mPower (B&W)	Westinghouse
Reactor Type	PWR	PWR	PWR
Electrical Output	45 MWe	180 MWe	225 MWe
Steam Generator Number	Two independent tube bundles		
Steam Generator Type	Vertical, Once through, helical tubes	Once through	Recirculating, Once through
Average Steam Generator Tube Length	22.3 m (73.2 ft)		
Steam Generator Tube Number	~1000		
Steam Cycle	Superheated	Superheated	
Turbine Type	3600 rpm, single pressure		
Steam Flow	56.1 kg/s (445,000 lb/hr)		
Thermal Power	150 MWt	530 MWt	800 MWt
Reactor Pressure & Core Exit Temperature	P < 10.4 MPa (1500 psi), 575 K (575 ºF)	825 psi, 608ºF	15.5 MPa (2250 psi), 310ºC (590ºF)
Primary Coolant Mass Flow Rate	~600 kg/s (4.76E6 lb/hr)	30 E6 lb/hr	100,000 gal/min
Refueling Intervals	30 months, UO2, 4.95% enriched	48months, <5% enriched	24months, 4.95% enriched
Containment	Underground	Underground	Underground
Emergency Core Cooling	Natural Circulation	Natural Circulation	Passive, Natural Circulation
Transportation	Rail, Truck, Barge	Rail	Rail, Truck, Barge

5

CANDU REACTOR SCHEMATIC



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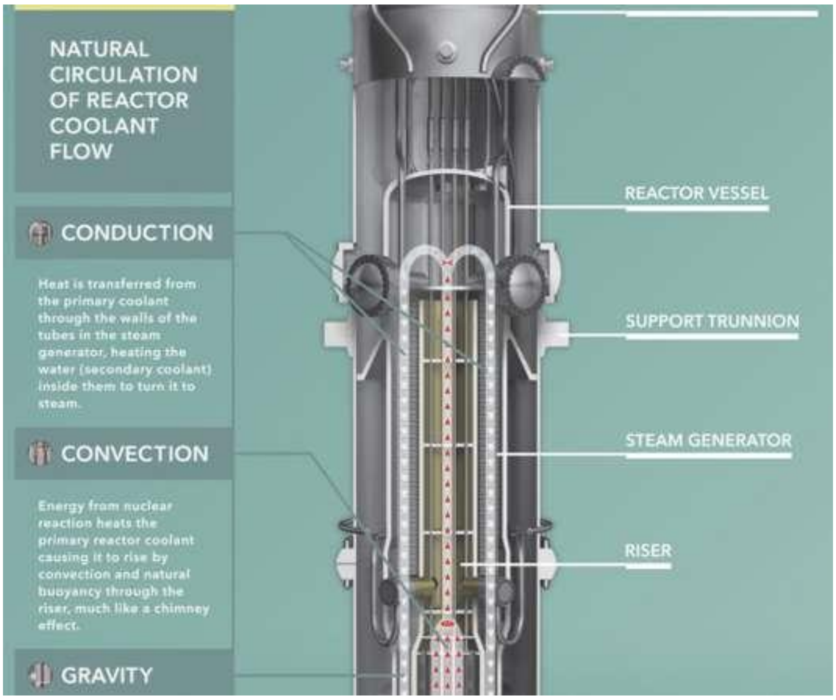
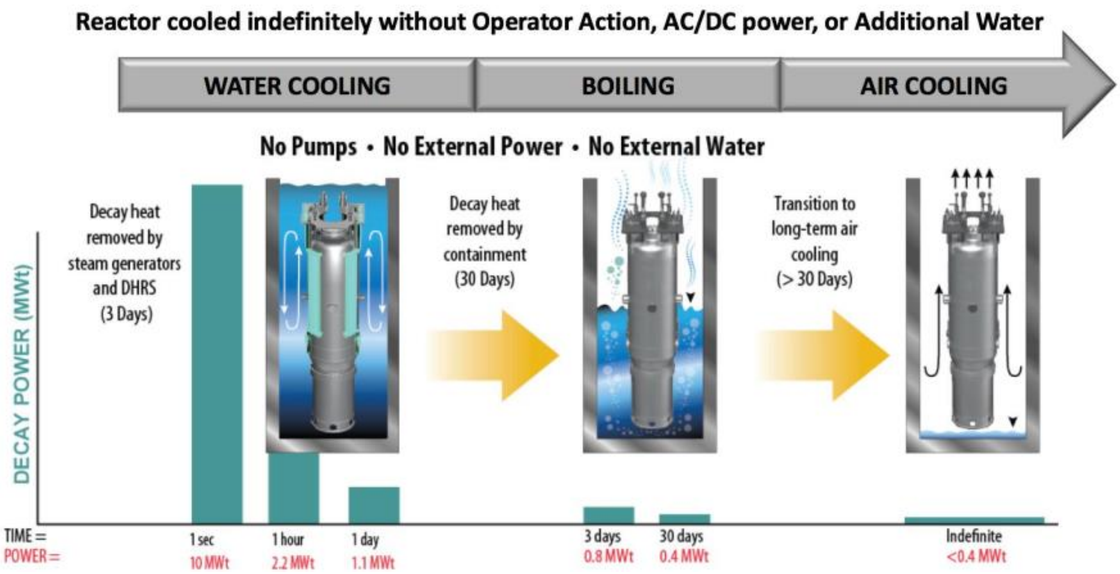
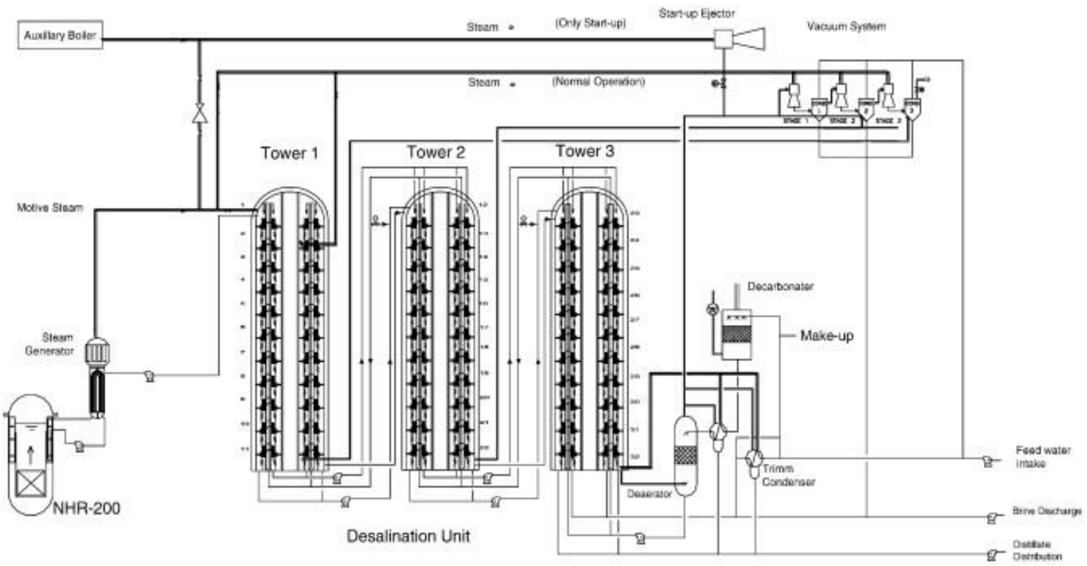

NATURAL CIRCULATION OF REACTOR COOLANT FLOW
CONDUCTION
Heat is transferred from the primary coolant through the walls of the tubes in the steam generator, heating the water (secondary coolant) inside them to turn it to steam.
CONVECTION
Energy from nuclear reaction heats the primary reactor coolant causing it to rise by convection and natural buoyancy through the riser, much like a chimney effect.
GRAVITY
REACTOR VESSEL
SUPPORT TRUNNION
STEAM GENERATOR
RISER

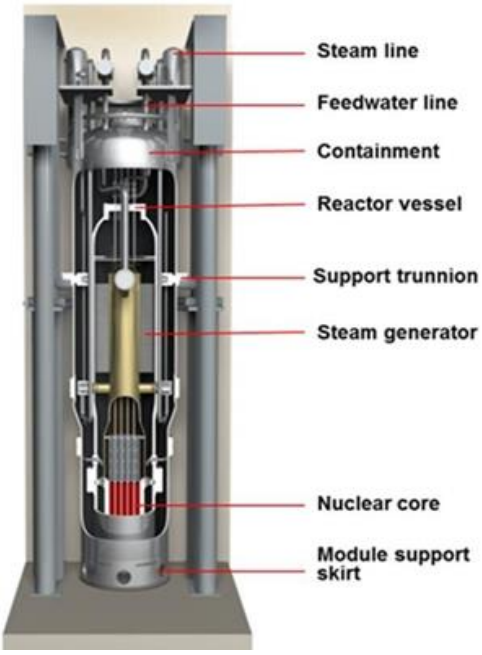
7


Reactor cooled indefinitely without Operator Action, AC/DC power, or Additional Water
WATER COOLING
BOILING
AIR COOLING
No Pumps • No External Power • No External Water
Decay heat removed by steam generators and DHRS (3 Days)
Decay heat removed by containment (30 Days)
Transition to long-term air cooling (> 30 Days)
DECAY POWER (MWt)
TIME =
POWER =
1 sec
10 MWt
1 hour
2.2 MWt
1 day
1.1 MWt
3 days
0.8 MWt
30 days
0.4 MWt
Indefinite
<0.4 MWt

8


Auxiliary Boiler
Steam
(Only Start-up)
Start-up Ejector
Vacuum System
Steam
(Normal Operation)
Tower 1
Tower 2
Tower 3
Motive Steam
Decarbonater
Make-up
Steam Generator
Feed water intake
Trimm Condenser
Deaerator
NHR-200
Brine Discharge
Desalination Unit
Distillate Distribution

9


Steam line
Feedwater line
Containment
Reactor vessel
Support trunnion
Steam generator
Nuclear core
Module support skirt

10

Pakistan's First Reactor KANUPP – 1

- KANUPP is now in its 47th year of operation
- It carried out safety improvements to bring it to current safety standards when it had completed its 30 year design life
- KANUPP is Pakistan's first nuclear power plant – A 137 MWe Pressurized Heavy Water Reactor (PHWR) the contract for which was signed by Dr. I.H. Usmani with Canada on 24th May 1965
- The reactor went critical on 1 August 1971, was connected to the grid on 10 December 1971 and formally entered into commercial operation in December 1972
- It was the state of the art plant of its time. It was one of the first NPPs which was direct-digitally controlled. Its fuelling machines were also controlled by 2 digital computers

11

Pakistan's First Reactor KANUPP – 2

- KANUPP has an interesting history from the very start
- At the start of East-Pakistan conflict in December 1971, the Canadian team left. The plant was restarted & kept operational by the KANUPP engineers (under the overall responsibility of one Canadian Commissioning Manager) our first lesson in self reliance
- In 1973, the Finance Minister instructed that KANUPP should be "self-financing", unheard of for a country's first NPP
- After the Indian nuclear explosion in 1974, Pakistan was being coerced into signing full-scope safeguards
- Pakistan considered this a violation of an existing tripartite safeguards agreement and did not agree to Canadian demands

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Pakistan's First Reactor KANUPP – 3

- In December 1976 Canada cut-off all technical support, equipment & access to information to KANUPP. Other western countries followed suit
- A fuel fabrication plant for KANUPP awaiting shipment at the port was also embargoed
- This started a full-fledged effort of self-reliance by KANUPP engineers & scientists
- At the same time indigenous efforts to build own fuel fabrication plant was started
- In the next 2 decades, highly sophisticated digital computers and instrumentation and control equipment were reverse-engineered, redesigned & replaced. Sensitive mechanical equipment was replaced and spares were fabricated
- The plant kept running.
- In 1977, a wonderful opportunity occurred and was not availed of. An opportunity which if availed of would have changed the whole face of Pakistan's nuclear power program from a turn-key buyer to a nuclear vendor

13

Duplication of KANUPP as an SMR & Specifically for Desalination

- Extensive operational experience of KANUPP
- Extensive design & development effort spanning 3 decades
- Self-reliant since end 1976
- Indigenously manufactured fuel
- Only low-pressure calandria not a RPV

The ideally suited for duplication as a small reactor/ NPP (This does not preclude Pakistan indigenously building bigger reactor of 300 Mwe size or greater !)

- KANUPP has indigenously built an MED desalination plant, taking 16 MWth (3.45 Kg/sec @ 120ºC) blod steam from the turbine & producing 1600 m^3 of water/day = 350,000 imperial gallons/day
- There are two versions of KANUPP that can be considered for duplication, as mentioned earlier

  Version 1 100 MWe or ≅ 300 MWth giving 45 million gallons/day
  Version 2 70 MWe or ≅ 200 MWth giving 33 million gallons/day
- It may be noted that these versions are desalination only. Power requirement for the MED Desalination units and for the Reactor/ NPP will need to be met by Diesel Generators

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NHR-200 INET Tsinghua University China

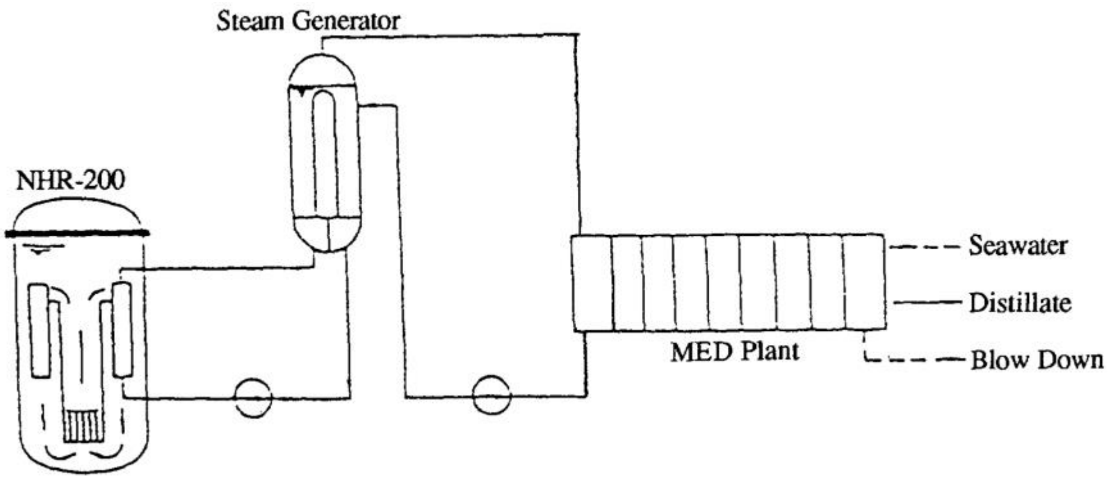
An Example of a Desalination Only Design of a SMR

- The NHR-200 is a large version of the experimental NHR-5 which was put into operation in 1989
- It has been chosen as a basis for the duplicate KANUPP. Since it is the only design which has a desalination only version
- The schematic and its main parameters are given in the next VGs

15

NHR-200 INET Tsinghua University China

An Example of a Desalination Only Design of a SMR



Schematic diagram (heat only) of NHR-200 desalination system

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NHR-200 INET Tsinghua University China
An Example of a Desalination Only Design of a SMR

Main parameters of NHR-200 nuclear desalination system with only heat production

Reactor power, MWt	200
Core outlet temperature, °C	210
Core inlet temperature, °C	150
Outlet temperature at intermediate circuit, °C	163
Inlet temperature at intermediate circuit, °C	135
Steam temperature, °C	130
Maximum sea water temperature, °C	
Capacity of MED unit, m^3/d	24,000
Number of MED unit	6
Maximum water production, m^3/d	144,000

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DETAILED DESCRIPTION
REACTOR – DESALINATION COUPLING

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Benefits of SMRs

- Low investment/ Reduced financial exposure
- Remote location
- Grid independent (in some cases)
- Proven coupling Technology/experience
- Reduced siting requirements
- Multipurpose /Dual purpose
- Safe and reliable operation with advanced innovative features

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Desalination Technologies

Thermal Technologies

- Multi Stage Flash Distillation (MSF)
- Multi Effect Distillation (MED)
  - VTE-MED (High Temp)
  - MED-VTC (Low Temp)

Membrane Technologies

- Reverse Osmosis
- MEDs use approximately 33% of electricity required by equivalent MSF, also operate at lower temperature (65°C vs 110°C) than MSF
- Seawater intake requirements can be upto 50% smaller than that of a similar sized MSF

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SMRs for Desalination Industrial Applications

- 90% industrial users need thermal power less than 300Mwt
- Half of the industrial users even demand thermal power in the range less than 10Mwt
- Japan has 13NPPs with desalination capacity of 1000-39000M3/d. Some of the these plants are operational since 1978
- Kazakhstan nuclear desalination plant of 80,000M3/d since 1999
- Pakistan and India operating nuclear desalination plants
- More than 400 reactor years experience of nuclear desalination

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Duplication of KANUPP as SMR Specifically for Desalination (Cont..)

- KANUPP (137MWe) started commercial operation in year 1972
- Plant is being operated safely without vendor support since 1976
- Detailed design and engineering knowledge of KANUPP type NPP during O/M without vendor support
- In year 2005, plant operating life was extended by 15 years following all national and international regulatory /safety requirements for operating NPP
- Plant operating life has been extended upto year 2019-2020
- 450M3/d RO based Seawater desalination plant operational since year 2000
- This was the first even seawater base desalination plant in country
- 1600M3/d indigenously designed MED based seawater desalination plant is operational since year 2009
- Capacity of MED plant can be extended upto 4500 M3/d with the addition of MED units

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Duplication of KANUPP as SMR Specifically for Desalination

- More than 45 years of O/M experience of KANUPP
- More than 17 years of O/M experience of RO based desalination plant
- More than 8 years of O/M of MED based desalination plant
- PAEC/KANUPP has complete technology for the design, manufacturing, testing and commissioning of indigenously developed MED plant
- Considering the electrical power requirements of the country (Energy Security plan 2030&2050) and construction of 1100MWe NPPs, role of another KANUPP type NPP won't be significant for national grid
- The extensive design and engineering knowledge of KANUPP, O/M of NPP and desalination plants (RO and MED based) can play a significant role for ever increased and acute potable water supply requirements of the in coastal area of the country
- Seawater desalination plants can also be coupled even with smaller capacity NPPs of 100MWt or smaller

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Alternate Options

An alternate to adapting KANUPP for desalination only is to use a research reactor e.g. the 42 MWth NRX (Canada) research reactor

If used purely for desalination it can yield 6 mgpd/day

A third viable option is to use a 5 – 10 MWth reactor (such as the NHR-5) as the heat source for MED desalination

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Concluding Remarks – I

Scarcity of water biggest challenge of this century
Glaciers are melting, rainfall pattern changing
Green areas will turn into deserts
Pakistan can no longer depend on the Indus
Our challenge as well as opportunity is the Arabian Sea !
Convert seawater into sweet water
Make Balochistan green and an economic powerhouse
How?
Through nuclear desalination
Had we done this earlier Gawadar would be a thriving megacity
We have the experience and various nuclear options ranging from a modified KANUPP, to an NRX type reactor to a smaller reactor to provide water for a city & for freckle fed irrigation farming
We also have more than a decade of experience of MED desalination & of its technology

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Concluding Remarks – II

ALL WE NEED IS THE WILL – BEFORE IT IS TOO LATE

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4. Media Coverage of the 10th Symposium of PAE

News Report in the DAWN Newspaper of April 30, 2018

FOUNDED BY QUAID-I-AZAM MOHAMMAD ALI JINNAH

DAWN

Monday
April 30, 2018
Sha'aban 13, 1439
KARACHI

Rs 22.00
30 Pages
Vol. LXXII No. 120
Regd. No. SS-022

www.dawn.com

'Small nuclear plants can end power crisis'

By Our Staff Reporter

KARACHI: Establishing mini nuclear power plants is the only sensible way ahead for Pakistan to overcome its energy generation problems and to ensure improved quality of life for its citizens.

This was emphasised by experts of nuclear development and atomic energy sectors in a symposium on 'Prospects of mini nuclear power plants in Pakistan' held at a local hotel on Saturday.

Organised by the Pakistan Academy of Engineering (PAE), the symposium was a well-attended affair and presented diverse and enriching views of the learned speakers.

In his welcome address, PAE President Dr-Ing Jameel Ahmed Khan pointed out that energy production was surging globally with 17 trillion kilowatt hour (kWh) of electricity being produced every year for which 90 million barrels of oil was burnt each day.

"We have to develop energy strategies to power our future. Our last 50 years of experience proves that nuclear energy is the safest and most efficient of all energy resources," he stated. "Therefore, mini and small nuclear power plants merit serious consideration for countries like Pakistan."

Saeed Alam Siddiqui, a member of the advisory council of the Pakistan Atomic Energy Commission (PAEC), said that the small modular reactor (SMR) technology was the answer to power and electricity problems as it was matured and viable.

That was followed by a detailed presentation on development of small modular reactors by Hidayatullah Khan, SMR technology manager at the PAEC.

It outlined the expected advantages as well as the challenges in the SMR development.

Other speakers including Chairman Emeritus Pakistan Nuclear Regulatory Authority Jamshed Hashmi, PAEC's Javed Aqleem and Waqar Butt also highlighted the early history and present status of nuclear reactors, the possibility of duplication of Kanupp in the context of incorporating SMR applications and its features.

The concluding feature of the symposium was a detailed video talk on SMR technology and off-grid distribution of power system by Mohammad Irshad, a consultant at Nuclear Power Plants, Lincoln, California.

He spoke about how the US and European countries were fast adopting SMR technology by establishing mini nuclear power plants and according to a safe estimate, a majority of the large nuclear power plants in those countries could be done away with by 2025.

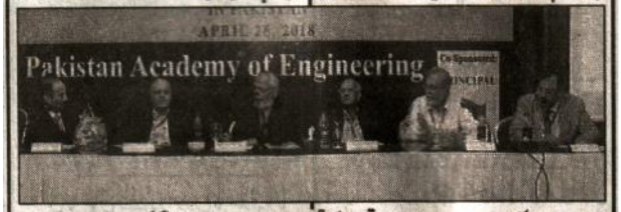
News Reports in the JANG Newspaper of April 26 & April 30, 2018

روزنامہ جنگ کراچی — پیر 13 شعبان المعظم 1439ھ 30 اپریل 2018ء

چھوٹے نیوکلیئر پاور پلانٹ توانائی پیدا کرنے کا حل ہیں، ماہرین

پوری دنیا میں توانائی کی پیداوار بڑھ رہی ہے، سمپوزیم

کراچی (اسٹاف رپورٹر) چھوٹے نیوکلیئر پاور پلانٹ پاکستان کی توانائی پیدا کرنے کا واحد ذمہ دارانہ حل ہے اور پاکستان کے شہریوں کی زندگی کو بہتر بنانے کا اظہار پاکستان کے نیوکلیئر ڈیولپمنٹ اور اٹامک انرجی کے ماہرین نے چھوٹے نیوکلیئر پاور پلانٹ کے پاکستان میں امکانات کے موضوع پر مقامی ہوٹل میں پاکستان اکیڈمی آف انجینئرنگ کے سمپوزیم میں کیا۔ ڈاکٹر جمیل احمد خان صدر پاکستان اکیڈمی آف انجینئرنگ نے اپنے استقبالیہ تقریر میں نشاندہی کی کہ پوری دنیا میں توانائی کی پیداوار بڑھ رہی ہے جس کے ساتھ 17 ٹریلین کے ڈبلیو ایچ Kwh کی بجلی پیدا کی جا رہی ہے۔ ہر سال جس کے لیے 90 ملین بیرل تیل جلایا جا رہا ہے۔ ہمیں اپنے مستقبل کیلئے توانائی کی پیداوار بڑھانا ہوگی۔ ہمارا پچھلے 50 سال کا تجربہ یہ ثابت کرتا ہے کہ نیوکلیئر انرجی سب سے محفوظ اور سب سے قابل طریقہ کار ہے اور چھوٹے اور بہت چھوٹے نیوکلیئر پاور پلانٹس پاکستان جیسے ممالک کے لئے اہم ہیں۔ ممبر چیئرمین ایڈوائزری کونسل پاکستان اٹامک انرجی کمیشن سعید عالم صدیقی نے کہا کہ SMR ٹیکنالوجی ہی ہماری توانائی اور بجلی کے مسائل کا واحد حل ہے کیونکہ یہ کرنا اب ممکن ہے۔ تقریب میں ہدایت اللہ خان نے ٹیکنالوجی کی تفصیلات سے آگاہ کیا۔ اس موقع پر جمشید ہاشمی، جاوید عظیم اور وقار بٹ نے بھی ٹیکنالوجی کی اہمیت پر روشنی ڈالی۔



منی نیوکلیئر پاور پلانٹ سمپوزیم کے موقع پر ڈاکٹر جمیل احمد خان، ہدایت اللہ اور دیگر گروپ (ف۔ر)

روزنامہ جنگ کراچی — جمعرات 9 شعبان المعظم 1439ھ 26 اپریل 2018ء

پاکستان اکیڈمی آف انجینئرنگ کے زیر اہتمام سیمینار ہوگا

کراچی (اسٹاف رپورٹر) پاکستان اکیڈمی آف انجینئرنگ کے زیر اہتمام "پاکستان میں چھوٹے نیوکلیئر پاور پلانٹس کے امکانات" پر ایک سمپوزیم 28 اپریل کو کراچی میں منعقد ہوگا۔ اہل علم حضرات بشمول سابقہ و موجودہ نیوکلیئر ماہرین اس اہم موضوع پر تقاریر کریں گے۔ حاضرین میں انجینئرنگ اور دوسرے شعبہ حیات سے تعلق رکھنے والے باصلاحیت حضرات کی شرکت متوقع ہے۔ پاکستان اکیڈمی آف انجینئرنگ کے صدر ڈاکٹر جمیل احمد خان (سابق وائس چانسلر این ای ڈی یونیورسٹی) خطبہ استقبالیہ پیش کریں گے۔ مقررین چھوٹے نیوکلیئر پاور پلانٹس کی ٹیکنالوجی، افادیت قومی اور بین الاقوامی تناظر میں پیش کریں گے۔

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News Reports in the NAWAE WAQT Newspaper of April 26 & April 30, 2018

پاکستان اکیڈمی آف انجینئرنگ کے تحت سمپوزیم سے ڈاکٹر جمیل احمد خان خطاب کررہے ہیں

چھوٹے نیوکلیئر پاور پلانٹس توانائی بحران کے خاتمہ کا واحد حل ہیں، ماہرین

کراچی (نیوز رپورٹر) چھوٹے نیوکلیئر پاور پلانٹس پاکستان میں توانائی بحران کا واحد ذمہ دارانہ حل ہیں۔ان خیالات کا اظہار پاکستان کے نیوکلیئر ڈیویلپمنٹ اور اٹامک انرجی کے ماہرین نے پاکستان اکیڈمی آف انجینئرنگ کے سمپوزیم میں کیا۔ سمپوزیم کا عنوان "چھوٹے نیوکلیئر پاور پلانٹ کے پاکستان میں امکانات" تھا۔ ڈاکٹر جمیل احمد خان، صدر پاکستان اکیڈمی آف انجینئرنگ نے اپنے استقبالیہ تقریر میں نشاندہی کی کہ پوری دنیا میں توانائی کی پیداوار بڑھ رہی ہے۔ جس کے ساتھ 17 ٹریلین کلوواٹ فی گھنٹہ بجلی پیدا کی جارہی ہے ۔ہمیں اپنے مستقبل کیلئے توانائی کی پیداوار بڑھانا ہوگی۔ اس موقع پر سعید عالم صدیقی، ممبر چیئرمین ایڈوائزری کونسل پاکستان اٹامک انرجی کمیشن، ہدایت اللہ خان منیجر نے بھی خطاب کیا۔

▶▶▶

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پاکستان اکیڈمی آف انجینئرنگ کے دسویں سمپوزیم سے مقررین خطاب کررہے ہیں

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