بسم الله الرحمن الرحيم

NPP Design Imperatives-SMR Perspectives

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PAKISTAN ATOMIC ENERGY COMMISSION

IAEA Technical Meeting on the Design, Experimental Validation and Operation of Small and Medium Sized or Modular Reactors (SMRs)

November 18-22, 2019, Islamabad, Pakistan

OUTLINE

1. Welcome, Introductory Remarks
2. Country Profile
3. SMR Features
4. Target Application and Acceptance Criteria
5. Regulatory & Licensing Framework
6. NPP Design Process
7. Design Phases
8. Application of Safety, Quality and ALARA

Welcome to all

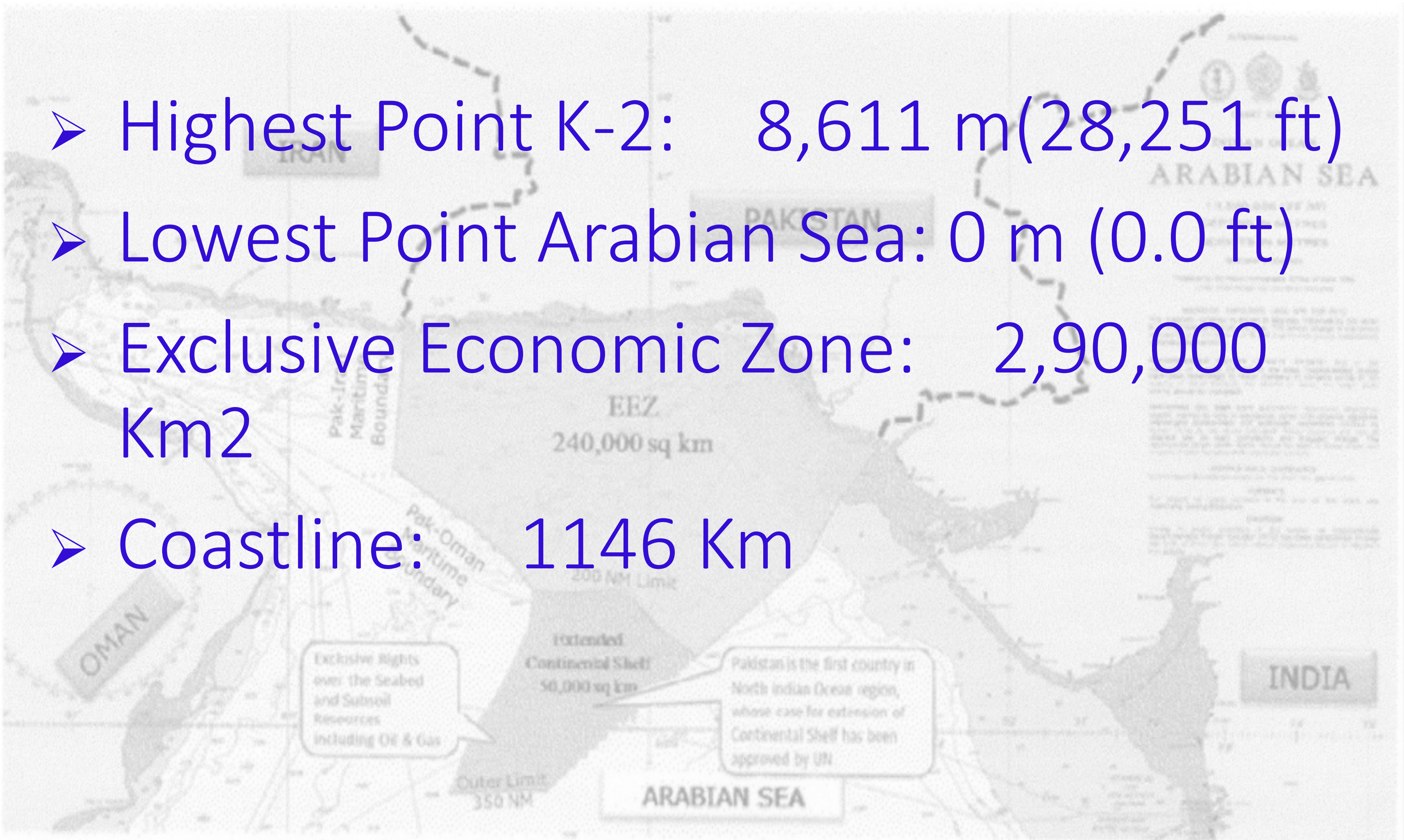
I appreciate the efforts of IAEA to meet one of it's statutory objectives:

> "seek to accelerate and enlarge the contribution of atomic energy to peace, health and prosperity throughout the world".

Country.........

- Area => 881,913 Square Kilo Meter
- Land---- 97.14 %
- Water---- 2.86 %
- Borders Total __ 7,307 Km
  - Afghanistan __ 2,430 Km
  - China __ 595 Km
  - India __ 3,323 Km
  - Iran __ 959 Km

Country………



- Highest Point K-2: 8,611 m(28,251 ft)
- Lowest Point Arabian Sea: 0 m (0.0 ft)
- Exclusive Economic Zone: 2,90,000 Km2
- Coastline: 1146 Km

Country.........

- Population ~218 million (Growth Rate of 2.1%)
    - 2.81 % of the world population (7.7 b)
    - Population density ~ 250 persons/Sqkm
    - Would be Double in Next ~ 35 Years
    - By 2050 it would be approx. 400 M

Country………

- Energy Consumption kWh/capita
  - Pakistan ~ 448
  - Europe ~ 5000
  - China ~ 4000
  - India ~ 800
  - Sri Lanka ~ 531

Country………

- Pakistan went through Energy Crises in recent past
- Need energy from clean sources (low-carbon emission) for a good energy mix (Hydel, Nuclear, Solar/Wind)

POWER PLANTS & TRANSMISSION SYSTEM

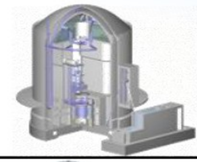
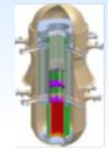
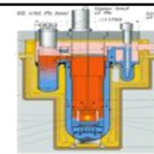
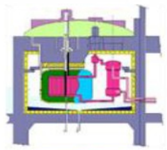
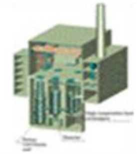
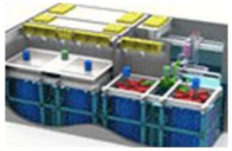
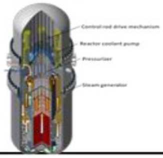
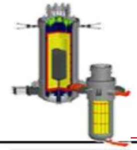
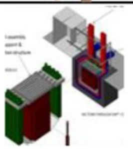
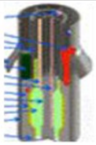
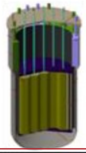
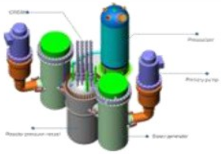
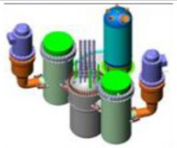
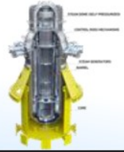
Features of SMRs

- Compact architecture
- Modularity of fabrication (in-factory)
- Reduced source term, smaller radioactive inventory
- Potential for sub-grade (underground or underwater) installation- more protection from natural (e.g. seismic or tsunami according to the location) or man-made (e.g. aircraft impact) hazards
- Multiple units on the same site.
- Suitable for remote regions and for specific applications such as mining or desalination
- Ability to remove reactor module or in-situ decommissioning at the end of the lifetime

Advanced SMR Reactors (Safety by design)

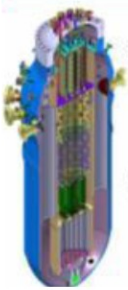
- Core Melt Exclusion Strategy(CMES)
- Inherently safer by design without the need for safety related backup electrical systems.
- large thermal inertia-provides more time for corrective actions
- wide operating margins with respect to safety limits
- Present the cutting edge nuclear technology
- Simplification in new designs (Complexity is root cause of problems)
- Simplification is being pursued with high priority, particularly operational safety.

Power Range of SMRs

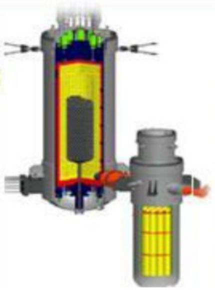
>301						• IMR • AHWR-300 • VBER-300 • GTHTR300 • IRIS
251-300						• DMS • GT-MHR • **EM²** • BREST-OD-300 • SC-HTGR
201-250						• Westinghouse SMR • FUJI • MHR-T • **ThorCon** • **LFTR**
151-200						• **mPower** • **SMR-160** • PBMR-400 • IMSR • Flexblue
101-150						• CAP150 • HTR-PM • MSTW • Mk1PB-FHR • SmAHTR
51-100						• ACP100 • SMART • MHR-100 • SVBR100 • ACPRSOS
0-50						• CAREM25 • NuScale • KLT-40S • HTMR-100 • G4M

SMRs Estimated Timeline of Deployment

Immediate Deployable



CAREM
Argentina



HTR-PM
China

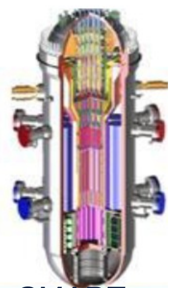
KLT-40S
Russian Federation

Under Construction

- CAREM-25
- KIT-405
  OKBM Afrikantov, Russian Federation
- HTR-PM
  INET, China

Near-term Deployable

ACP100
China



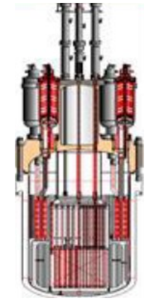
SMART
Re bi!C of Korea

NuScale

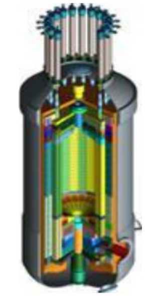
Certified or at Advanced Design Stage

- SMART
  KAERI, Republic of Korea
- RITM-200
  OKBM, Russia
- PRISM
  GE-Hitachi, USA
- PBMR-400
  PBMR, South Afca
- BREST300-0D
  NIKIET, Russia
- 4S
  Toshiba, Japan
- ACP100
  CNNC, China
- NuScale
  NuScale Power, USA
- mPower
  B&W, USA
- GTHTR300
  JAEA, Japan
- SVBR-100
  AKME Engineering, Russia
- ABV-6M
  OKBM, Russia

Mid to Longer-term Deployable



UNITHERM
Russian Federation



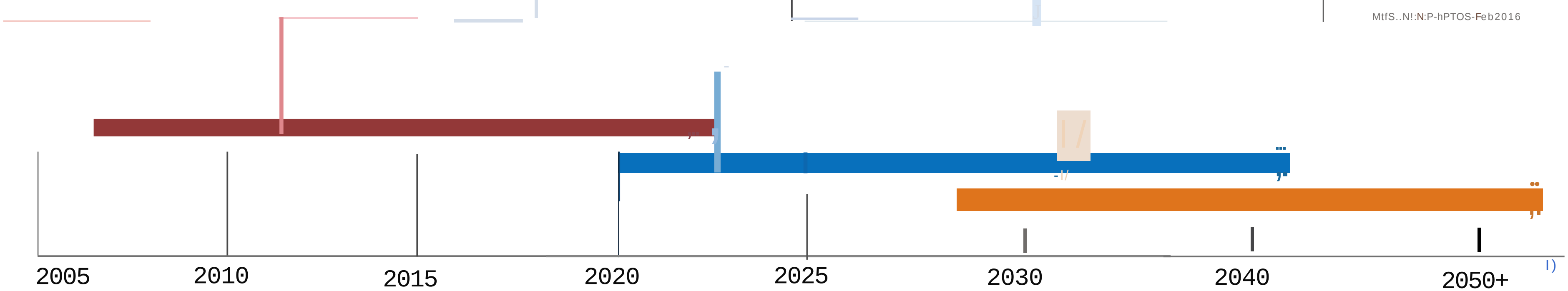
HTMR100
South Africa

SMR160
United States of America

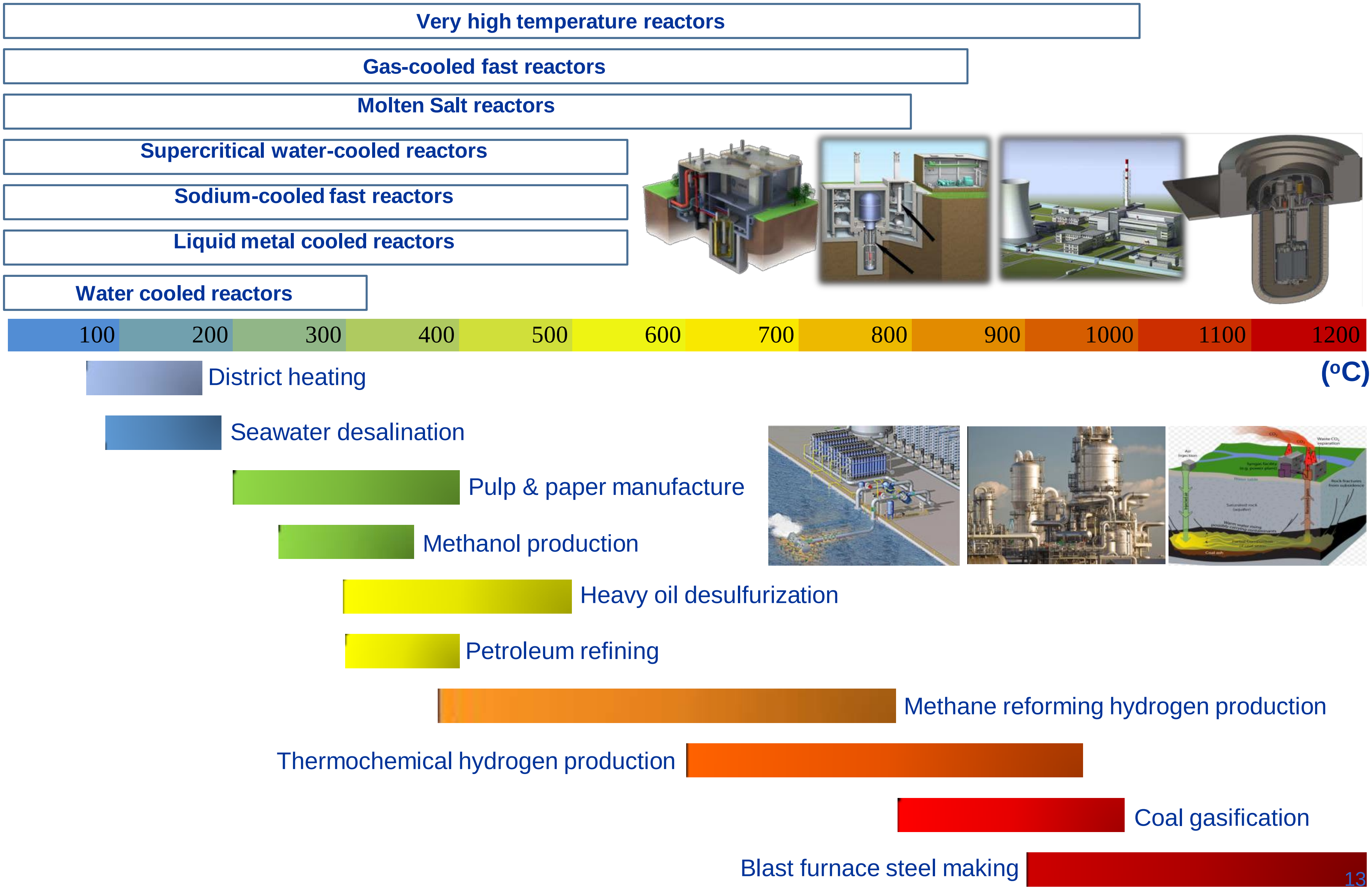
Conceptual Design for Future Deployment

- AHWR300
  BARC, India
- Flexblue
  DCNS, France
- RIS
  IRIS International Consortium
- OMS
  Hitachi-GE, Japan
- MR
  MH, Japan
- WER-300
  OKB Gidropress, Russia
- Westinghouse SMR
  Westinghouse, USA
- SMR160
  Holtec, USA
- VK-300
  NIKIET, Russia
- Th-100
  STL, South Africa
- SC-HTGR
  AREVA, France
- G4M
  Gen4 Energy, USA

MtfS..N!:N:P-hPTOS-Feb2016

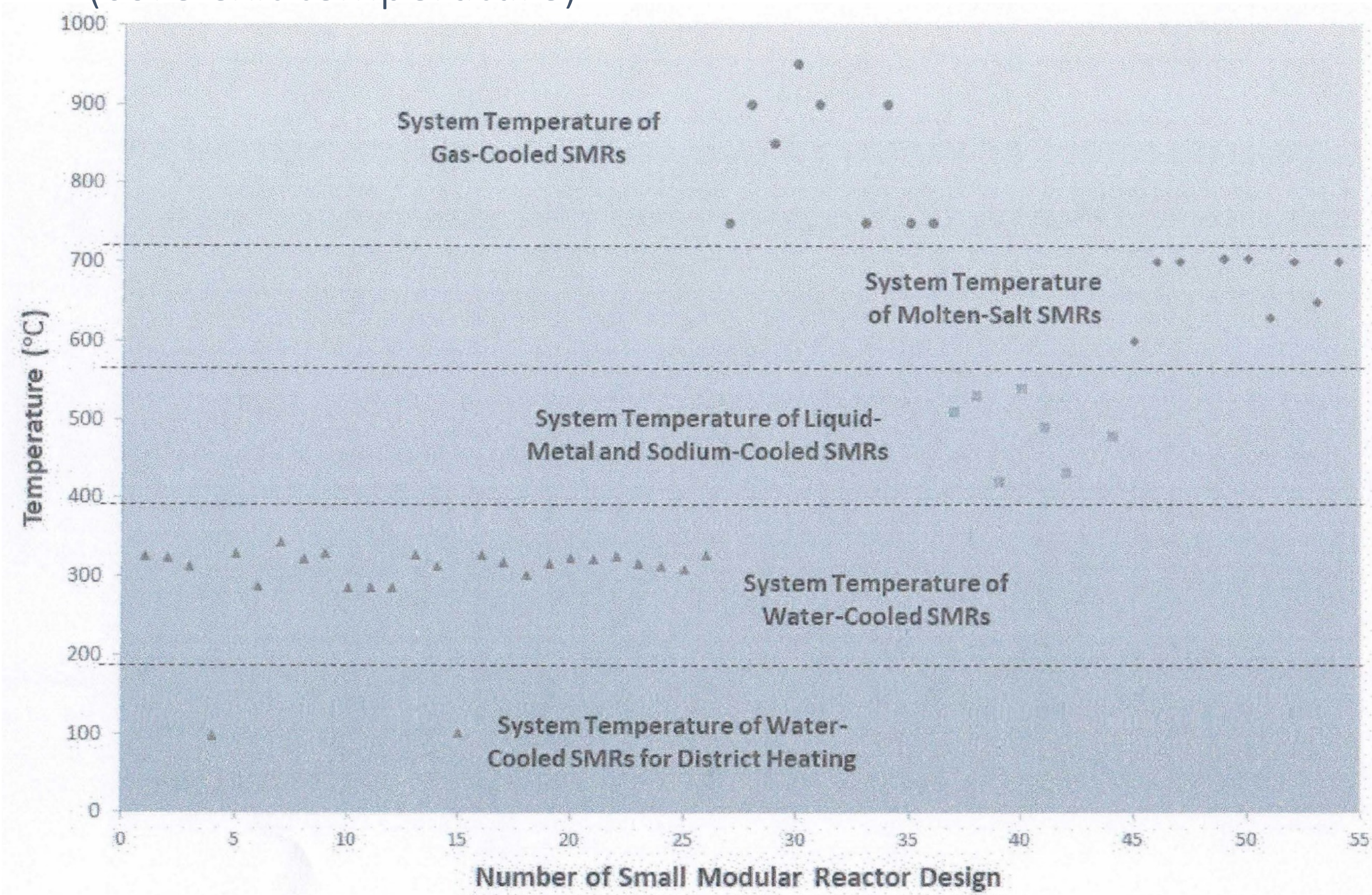


SMR for Non-Electric Applications



SMR Concepts Under Development

(core exit temperature)



Target Application and Acceptance Criteria

- SMR are offering one of the promising solution for the future needs of Pakistan.
- Remote areas along CPEC, less-developed/far-flung areas in the country
- Along coastline with option of seawater desalination
- Current PAK- Regulations Issued by PNRA => for Land based facilities only
- PNRA may require to amend the Regulations to Include the SMRs
- Codes & standards mutually agreed with PNRA Such as 10 CFR, ASME, IAEA & NRC RGs etc.

Acceptance Criteria (Pak-910)

ALARA &
Regulatory Dose
Rate Limits
during Normal
Reactor Operation

PAK-904

PAK-911

PAK-912

Exclusion Area Boundary

Radiation Dose Limit of 250mSv in 2-hrs After Postulated Accident Shall not be exceeded

Low Population Area Boundary

Radiation Dose Limit of 250mSv After Postulated Accident Shall not be exceeded

Pak-914, dose limit at UPZ 100mSv in 7days

Control Room Dose Limit of 50mSv (Design Basis Accident)

Uncontrolled Area Dose Rate limit(Adopted) 0.8 μSv/hr

Acceptance Criteria(Pak-911) Probabilistic

- CDF< 10^{-5}
- Off-site radiation release frequency < 10^{-6}
- Risk of early deaths in the vicinity of NPP(within 2km)< 0.1%
- Risk of latent health effects (within 15km) <0.1% of all the sum of prompt fatalities from accidents in all other energy sources
- Max. tolerable risk to any member of public due to NPP< 0.1 delayed fatalities per GWe year

Regulatory & Licensing Requirements

PART II

Statutory Notification (S.R.O)

GOVERNMENT OF PAKISTAN

PAKISTAN NUCLEAR REGULATORY AUTHORITY

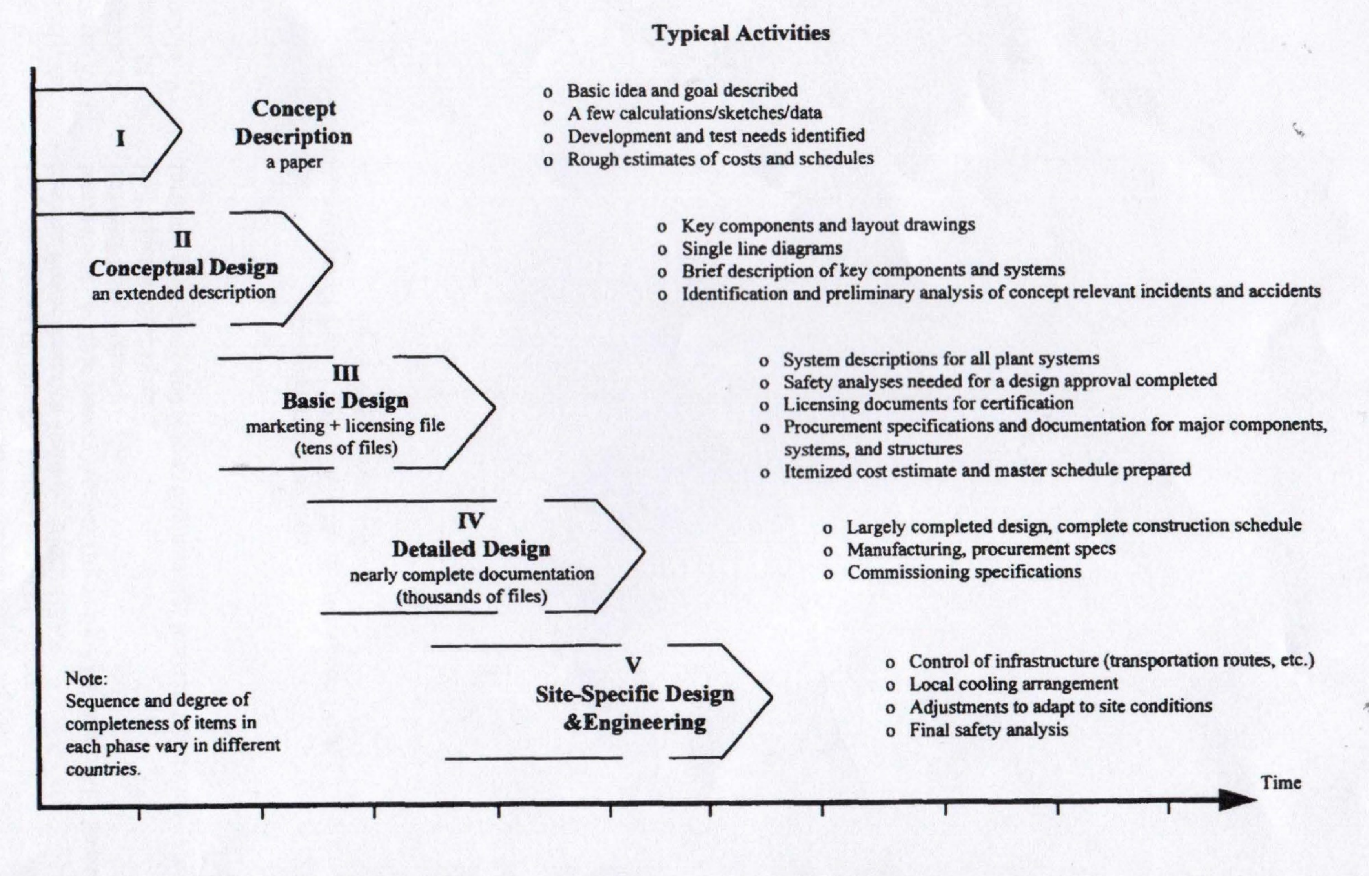
NOTIFICATION

Islamabad, the 11th January, 2002

S.R.O. 43(I)/2002. — In exercise of the powers conferred by Section 16 of the Pakistan Nuclear Regulatory Authority Ordinance 2001 (III of 2001), Pakistan Nuclear Regulatory Authority is pleased to make the following Regulation:

1. Short title and commencement—(1) This regulation may be called "Regulation on the Safety of Nuclear Power Plant Design (PAK/911) (Rev. 1)".
(2) This regulation extends to the whole of Pakistan.
(3) This regulation shall come into force at once.
(4) This regulation shall also apply to all the establishments of the Pakistan Atomic Energy Commission.

Design Development Phases (IAEA –TECDOC-936, 1997)



Design Development Phases ….

- PC-II: (Concept description) pre-start phase of feasibility stage
- (PC-I): (Conceptual design description Project Approval and Financial allocations of Resources and Identification of Milestones
- PC-III(A): Quarterly progress reports,
- PC-III(B): Financial and progress on monthly basis
- PC-IV: Report for completion
- PC-V: Evaluation stage of Project

Design Process

- **Design Inputs** (Functional requirements, Specific Standards, Regulatory requirements, commitments)
- **Design constraints** (Engineering procedure, General Code & Standards, Required design methodologies)
- **Design Analysis and calculations** (analysis, studies, Calculations, reports)
- **Design output Documents** (Specifications, Drawings, set points, testing & functional requirements, performance criteria, System design description)
- **Design output requirements** (Safety & environmental requirements, other requirements

Design Inputs

- Design inputs should be identified and documented
- Subject to review
- Any changes should be identified, documented, approved and controlled in a timely manner.

Application of Safety, Quality and ALARA

- Application of safety, quality and radiation protection Regulations, standards and regulatory guides
  - Safety =>First
  - Quality =>Must
  - ALARA=> Lever to lift the safety and quality
- Defense in depth approach
- Multiple physical barriers
- Core Melt Exclusion Strategy

Application of Safety, Quality and ALARA

Safety

Objectives & Principles (SF-1)

Requirements (SSR-2/1)

GDC (10 CFR 50)

I. Overall Requirements:
II. Protection by Multiple Fission Product Barriers
III. Protection and Reactivity Control Systems
IV. Fluid Systems
V. Reactor Containment
VI. Fuel and Radioactivity Control

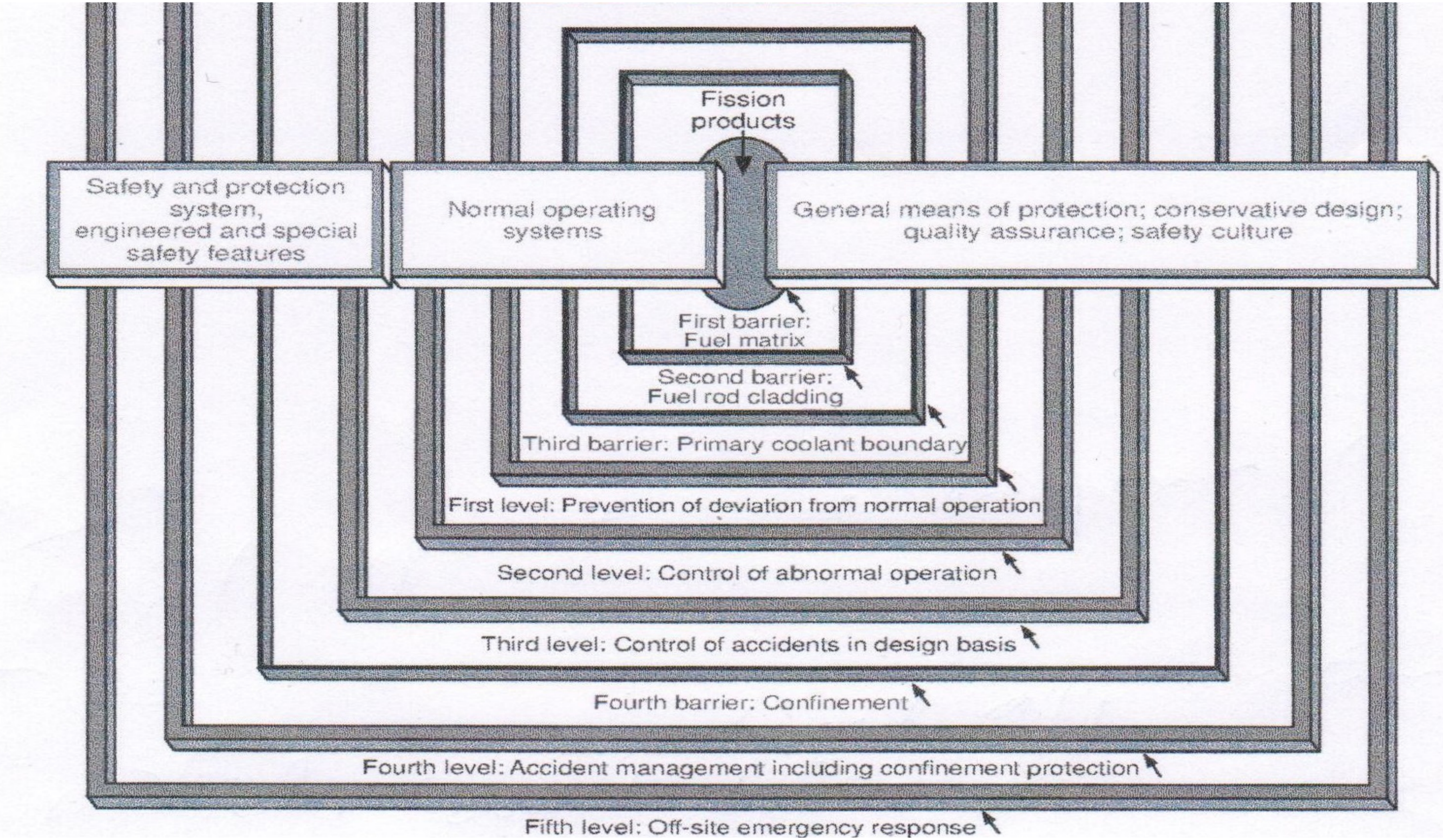
Reactor Design	10
Reactor inherent Protection	11
Suppression of Reactor Power Oscillations	12
Instrumentation and Control	13
Reactor Coolant Pressure Boundary	14
Reactor Coolant System Design	15
Containment Design	16
Electric Power Systems	17
Inspection and Testing of Electric Power Systems	18
Control Room	

Application of Safety, Quality and ALARA

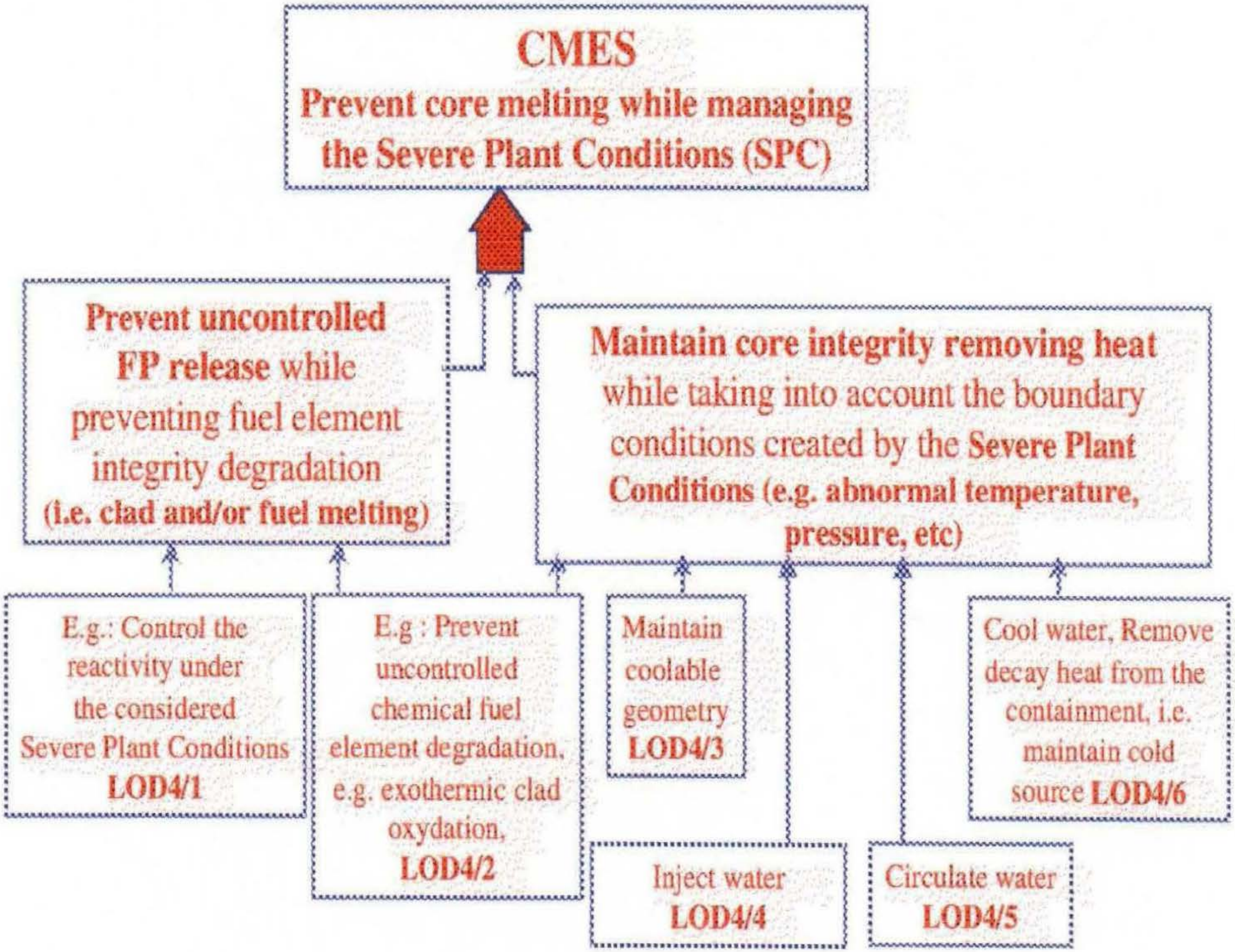
Criterion 10 -- *Reactor design*. The reactor core and associated coolant, control, and protection systems shall be designed with appropriate margin to assure that specified acceptable fuel design limits are not exceeded during any condition of normal operation, including the effects of anticipated operational occurrences.

Defense in Depth (INSAG-10)

(International Nuclear Safety Advisory Group)



Core Melt Exclusion Strategy



Safety Requirements and Categories – SSR-2/1 2016

There are 82 requirements in following categories:

1. Management of Safety in Design
2. Principal Technical Requirements
3. General Plant Design - Requirements
4. Design of Specific Plant Systems – Requirements

Interpretations of Safety Requirements in Design

1. Plant states to be considered in design
2. DEC’s to be included in design
3. Design basis of plant requirements vs beyond design basis
4. DiD for the spent fuel pool
5. Independence of levels of DiD
6. Prevention of common cause failure
7. Reliability of heat transfer for ultimate heat sink
8. Design margins and cliff edge effects
9. Interpretation of the concept of practical elimination
10. Design for external hazards
11. Use of mobile source of electric power and coolant
12. Acceptance criteria for different plant states

Initiating Event Groups and their Contributions to Total CDF for Chasnupp-2

No.	Initiating Event (Group)	IE Label	CDF (1/yr)	Contribution (%)
1	Loss of Offsite Power	LOOP	3.94E-06	25.2
2	Small Break LOCA	SLOCA	2.14E-06	13.7
3	Loss of Component Cooling Water	LOCW	1.79E-06	11.5
4	Steam Generator Tube Rupture	SGTR	1.48E-06	9.5
5	General Transients	GTRAN	1.16E-06	7.4
6	Loss of DC Power	LODC	7.01E-07	4.5
7	Loss of Instrument Air	LOIA	5.62E-07	3.6
8	Loss of Main Feedwater	LOMF	5.05E-07	3.2
9	Large Break LOCA	LLOCA	2.96E-08	0.2
10	Others		3.31E-06	21.2

Pursuance for SMR

- Based on technical experience, capabilities and design confidence, Pakistan has the ability to pursue for indigenous development of SMRs
- Due to urgent needs of Energy Crisis, acquisition of SMRs is necessary
- Owing to innovative ideas in development of SMRs, collaboration among the technically capable countries is viable

IAEA

IAEA can play a role in resolving the big Nuclear Issues: Meltdown, Waste and War

Thank you