SMALL MODULAR REACTORS (SMRs)

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

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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)

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

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

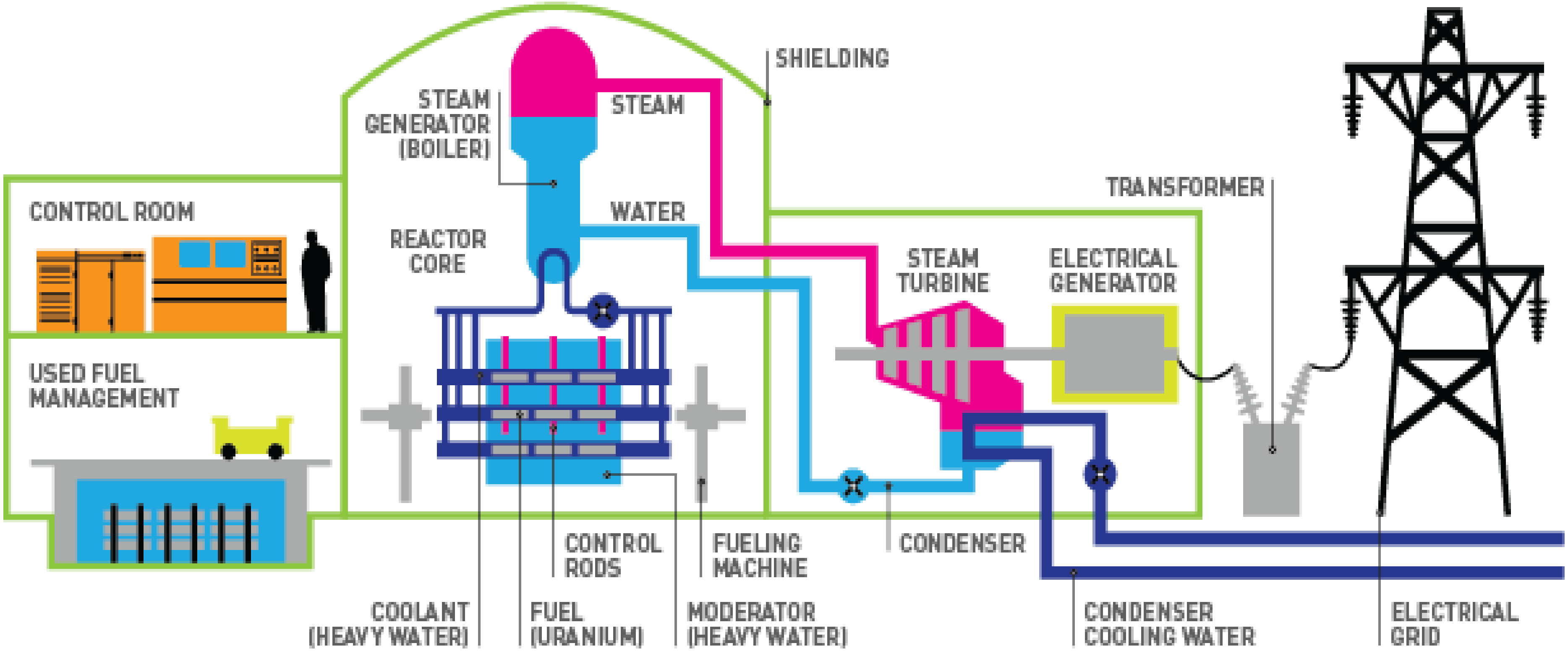
120,000 m^3/ day = 26 Million gallons/day

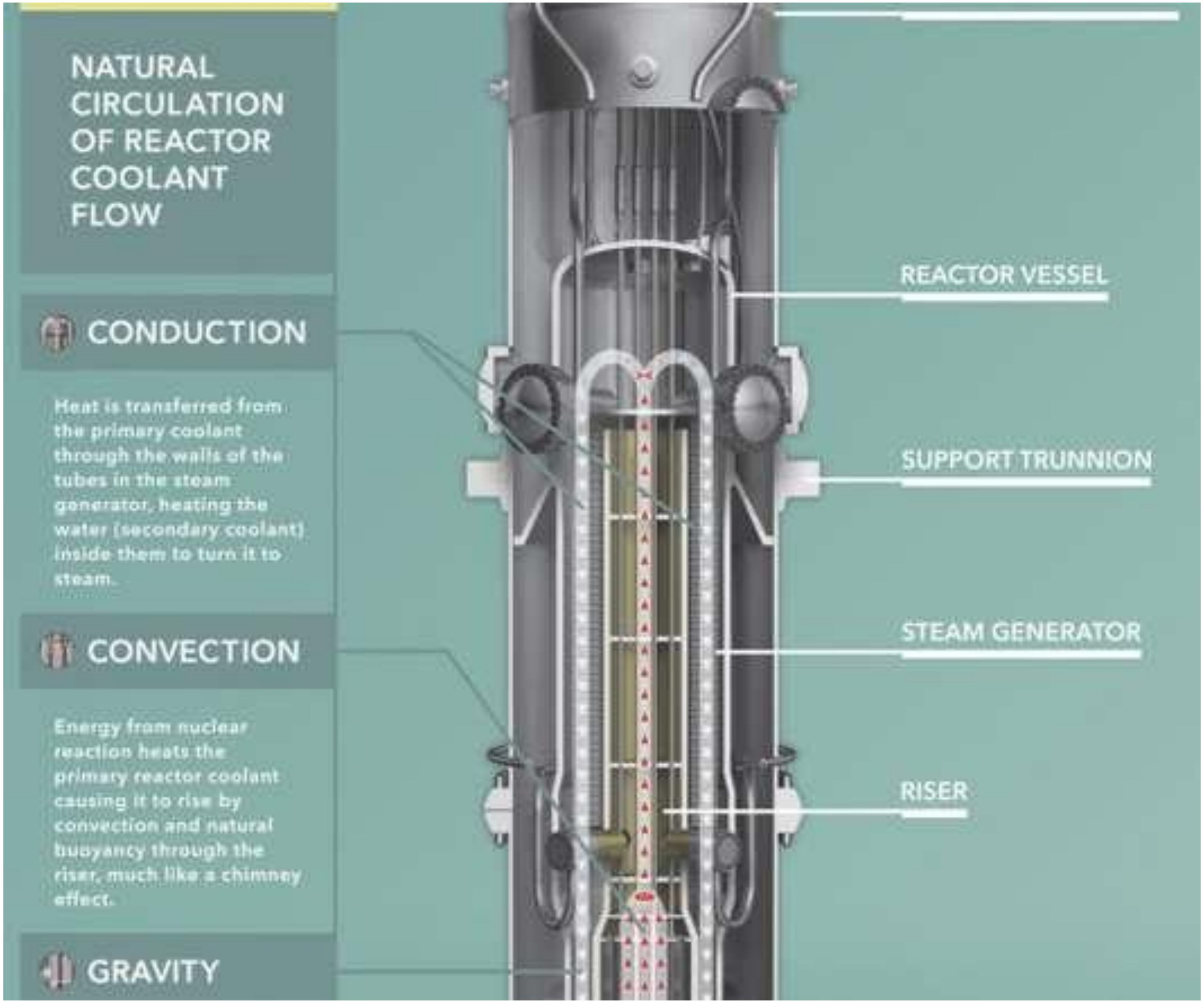
Early History & Present Status of Nuclear Reactors

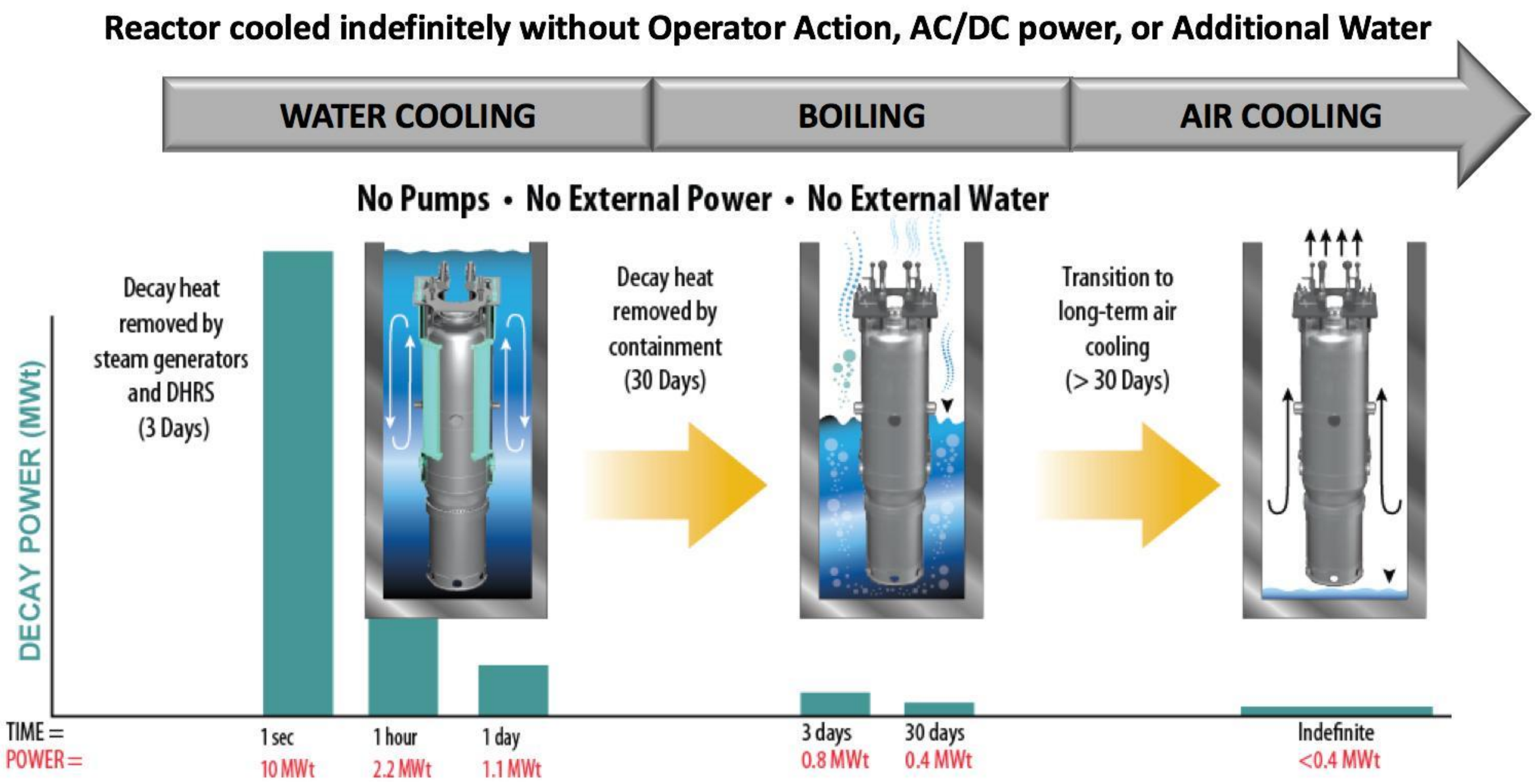
Some Common Characteristics of Three (3) SMRs

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 ^{o}F)	825 psi, 608^{o}F	15.5 MPa (2250 psi), 310^{o}C (590^{o}F)
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

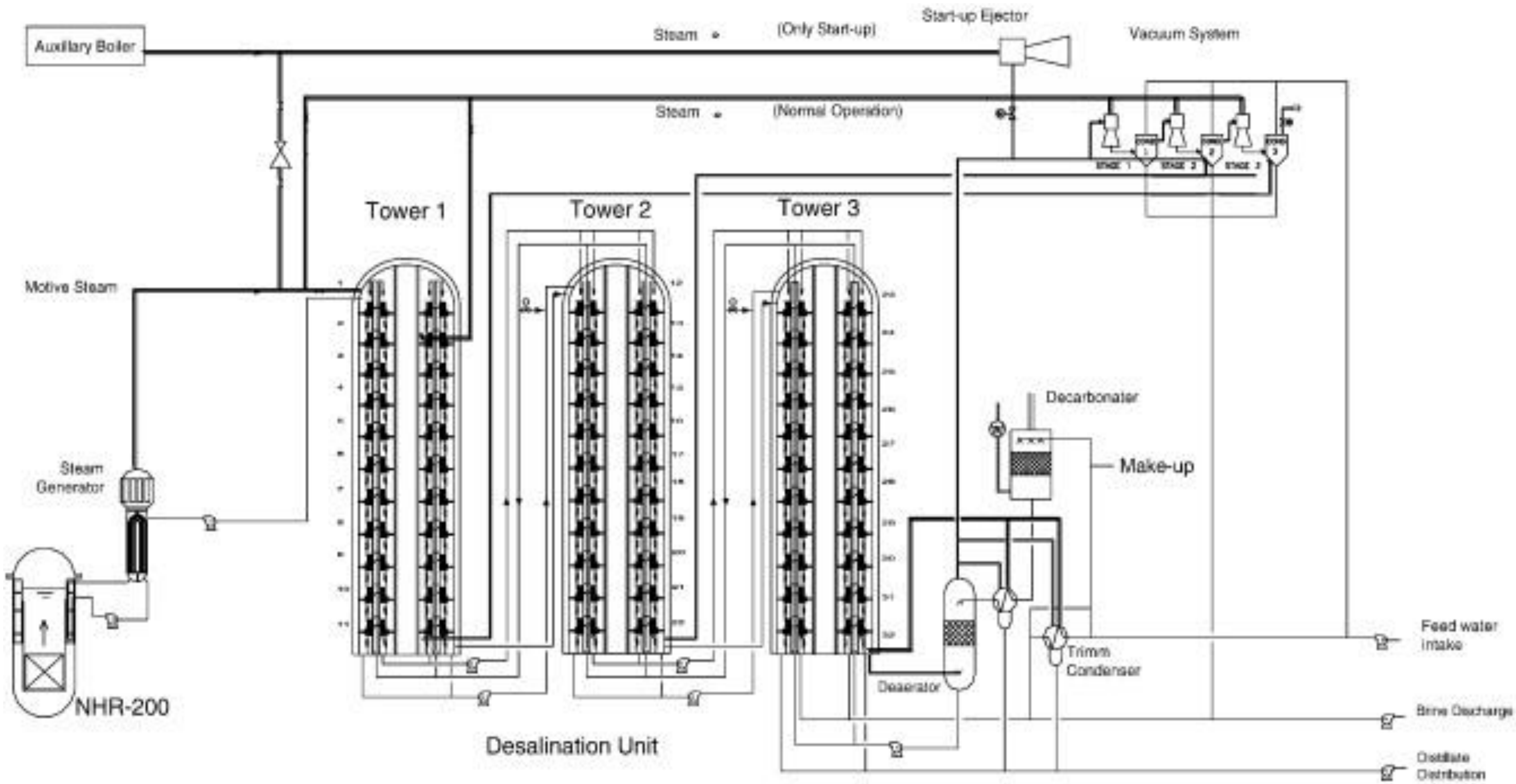
CANDU REACTOR SCHEMATIC



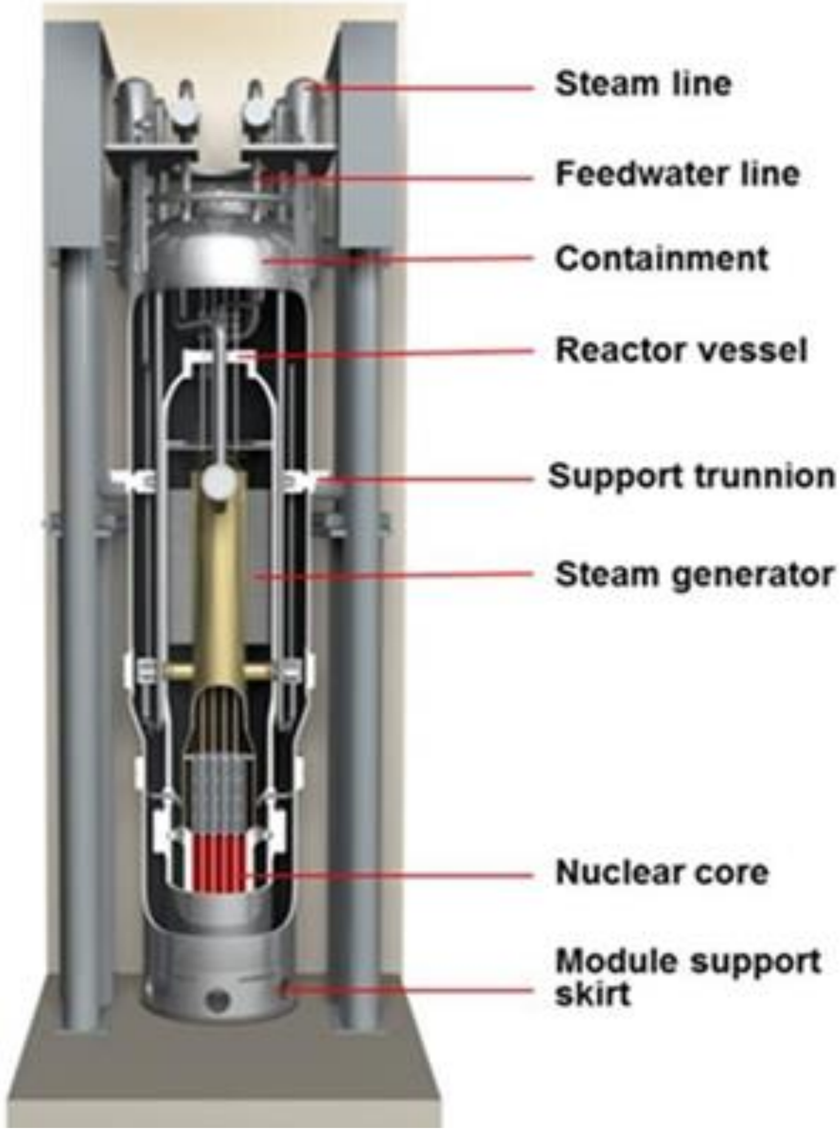

NATURAL CIRCULATION OF REACTOR COOLANT FLOW
CONDUCTION
Heat is transferred from the primary coolant through the walls of the tubes in the steam generator, heating the water (secondary coolant) inside them to turn it to steam.
CONVECTION
Energy from nuclear reaction heats the primary reactor coolant causing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



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



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


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

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

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

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

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 !)

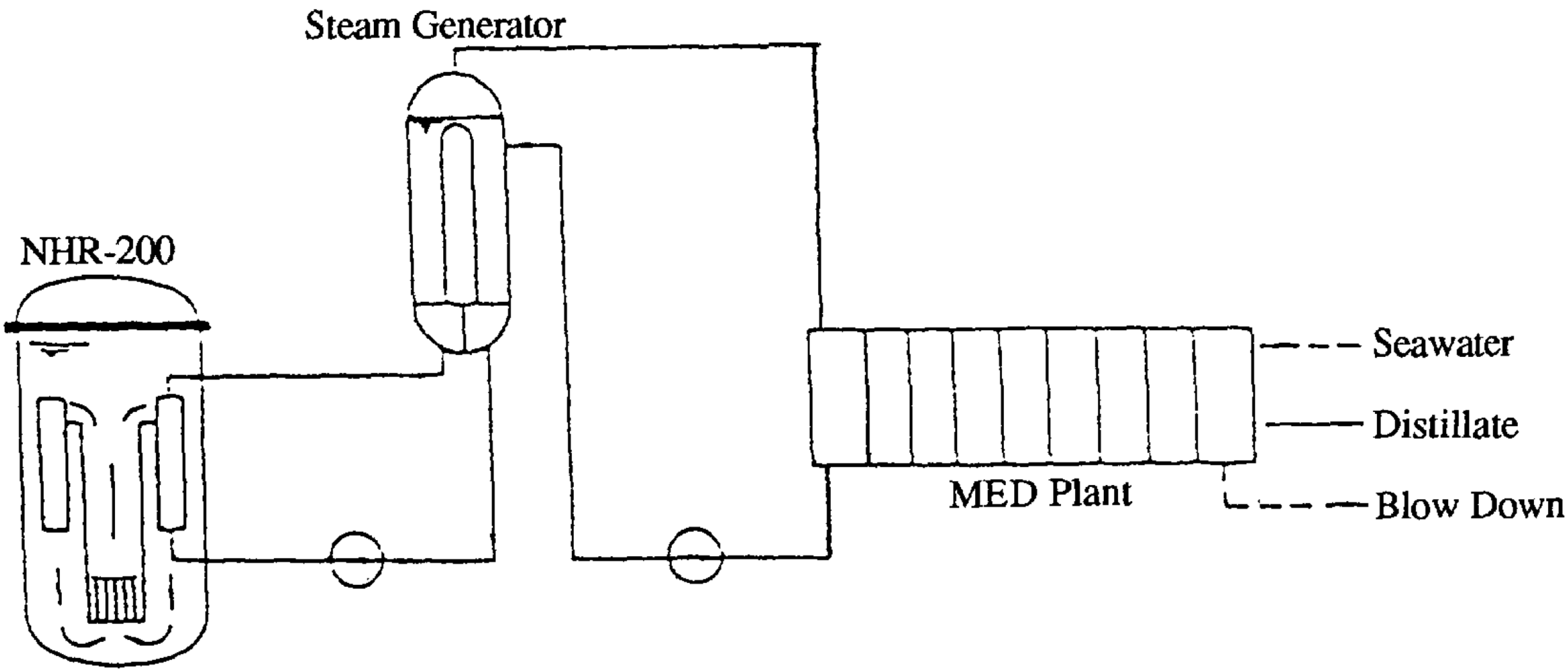
- KANUPP has indigenously built an MED desalination plant, taking 16 MWth (3.45 Kg/sec @ 120^{o}C) blod steam from the turbine & producing 1600 m^3 of water/day = 350,000 imperial gallons/day
- There are two versions of KANUPP that can be considered for duplication, as mentioned earlier

  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

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

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

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

DETAILED DESCRIPTION
REACTOR – DESALINATION COUPLING

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

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^{o}C vs 110^{o}C) than MSF
- Seawater intake requirements can be upto 50% smaller than that of a similar sized MSF

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

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

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

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

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

Concluding Remarks – II

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