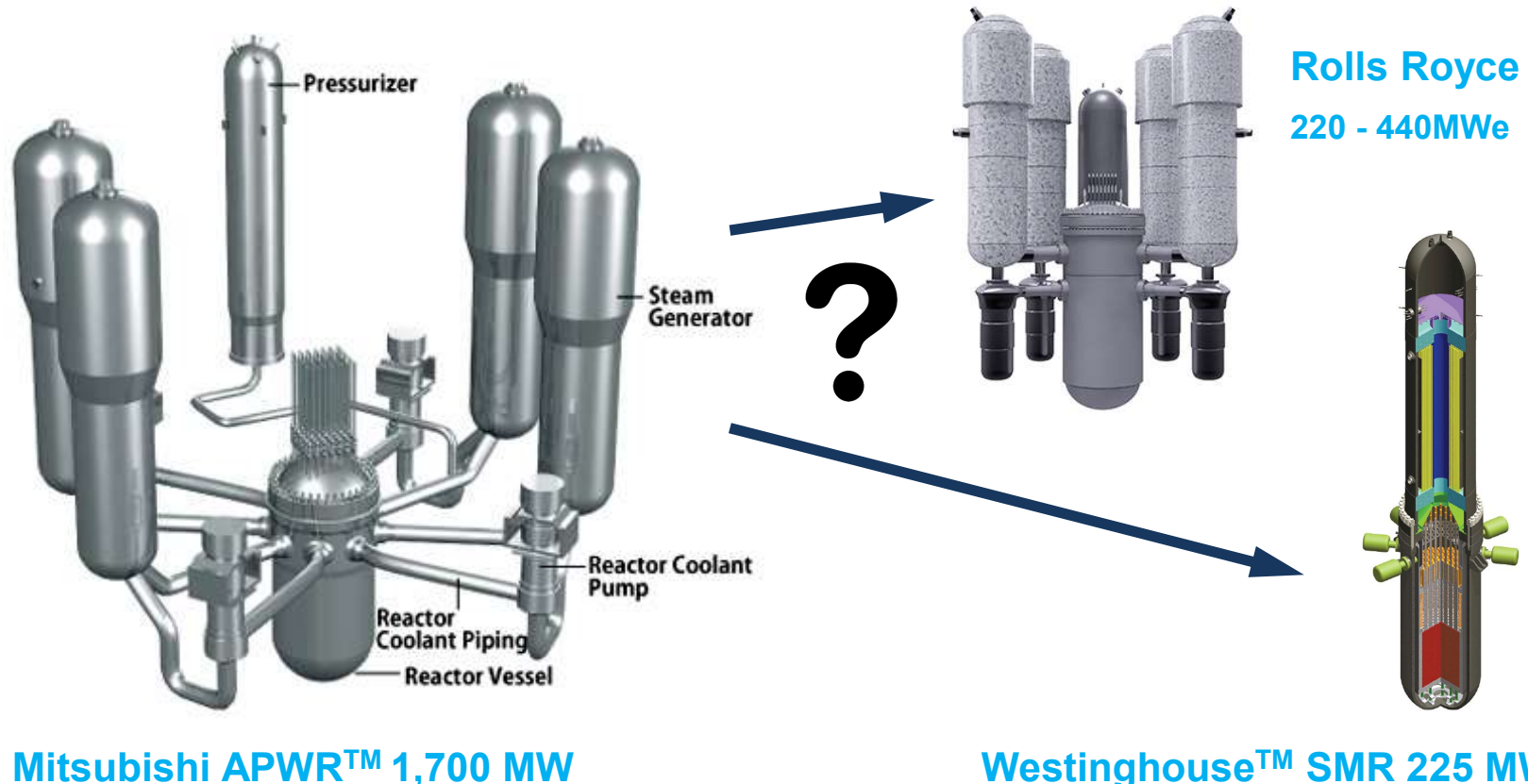


Development of User & Technical SMR Requirements for User Countries



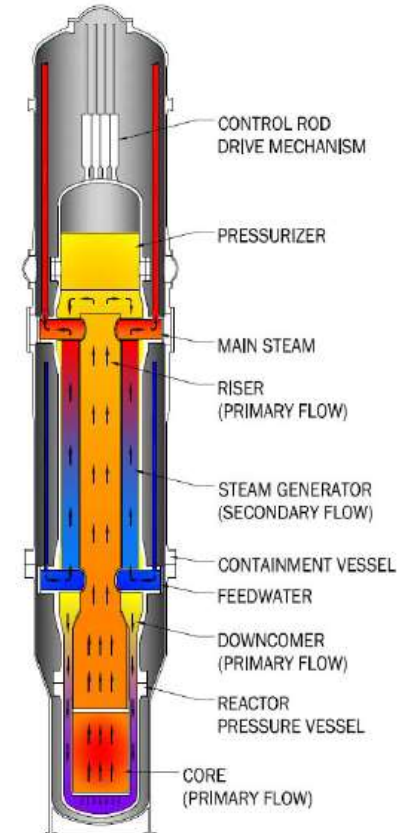
Graphics: Mitsubishi Heavy Industries & Westinghouse SMR



Step 1: User Requirements Identification

Safety Considerations

- Fundamental safety considerations
 - Negative Reactivity thermal coefficient
 - Control of Reactivity
 - Sufficient forced convection and passive cooling
- CDF (Core damage frequency) of SMR $\leq$ best large new build NPP
- Grace period $\geq$ 72 hrs
- Design against single failure mode
- Design to take on lessons learnt from Fukushima accident
- Ability for SMR design to withstand DBAs
- Ensure that the philosophy of defence in depth is abided



NuScale
(50 MWe)

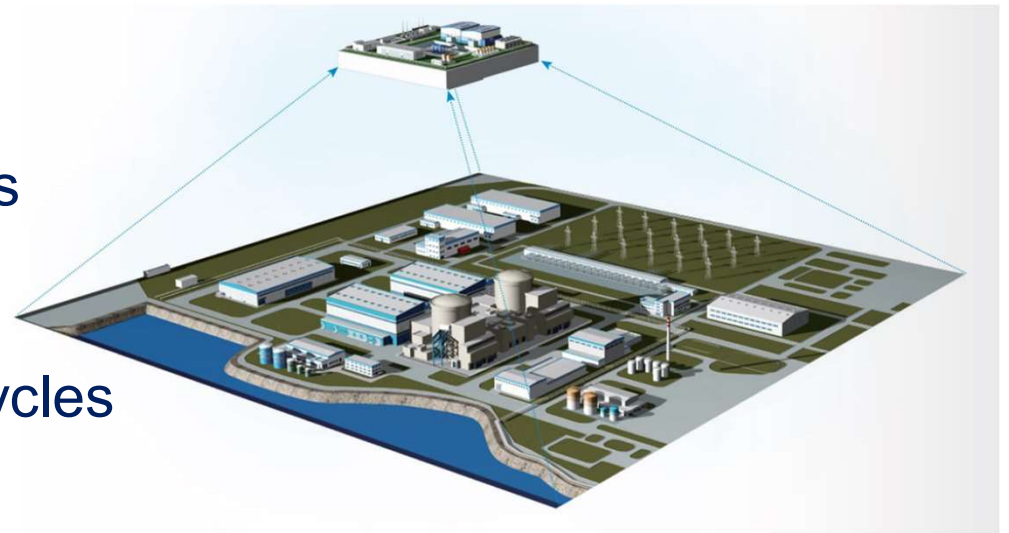
Operational Requirements



- deployable in 10 year time frame as Nth of a kind (NOAK)
- High capacity factor
- Long refueling cycle (3 years possible?)
- Ability to load follow to accommodate for large renewables deployment, achieved either by:
 - Modular-based operation (ie. Many modules, on or off)
 - Or / and by large power ramping $\partial Q / \partial t$

Siting Requirements

- Reduced EPZ
- Seismic tolerance $\geq 0.3g$?
- Replacement for est. nuclear plants
- Retrofit for old coal plants
- Remote deployment w/ long fuel cycles
- Smaller footprint / visual impact
- Footprint per MWe comparable to large NPPs
- Transportable by land or rail (for in-land sites)
- Grid compatibility / minimal grid build-out
- Possibility of dry cooling



Non-electrical production

- Industrial heat ($\geq 500^{\circ}\text{C}$)
Eg. For Shale oil or Tar Sands processing
- Coupled to Thermal Storage
- Desalination
- Hydrogen production
- District heating ($< 200^{\circ}\text{C}$)

Additional Consideration:

- Security needs identification & planning

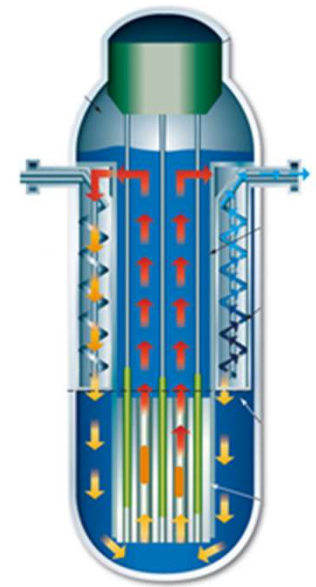




Step 2: Derived Technical Requirements from user identified priorities

Choice of SMR design

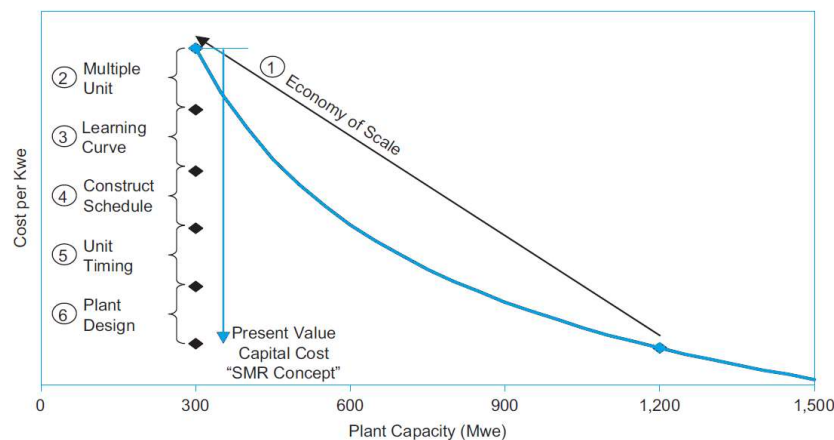
- Proven technologies (LWR or otherwise for NOAK)
- Passive safety
- Minimal fuel movement
- Minimal water use per MWe
- Reduced EPZ to site boundary
- Enhanced protection against external hazards
- Assembly-line manufacture (cost reduction perspective)
- Modular in deployment (many units on one site or dispersed)
- Modular in build (modular parts shipped to site for assembly)
- Ability to procure fuel for the life of the reactor
- To consider demonstrated designs that can be modified.



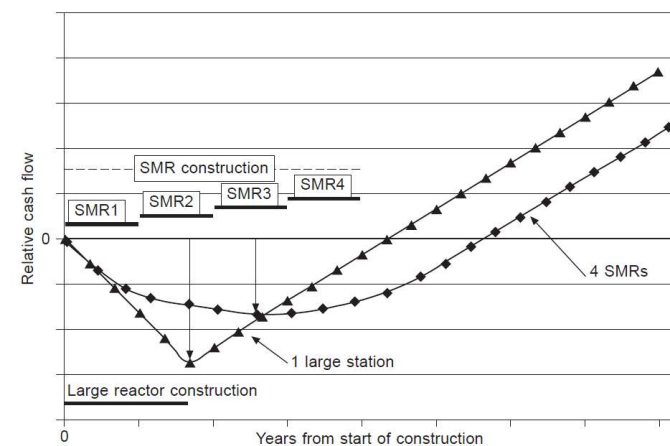
CAREM
(32 MWe)

Economic Considerations

- Smaller capital outlay per unit w.r.t Large new build NPPs
- Price driven down by scale-of-multiples
- High fuel utilisation
- Flexible deployment (deployment in series)
- Is Capex per kWe competitive against alternative source available?
- (ie. Site specific)



Reduction of cost by scale of multiples (Mycoff et al., 2011)



Flexible Deployment (Carelli, 2015)

Future Work

1. Develop the 1st draft of specific User's Requirements Document (RD): the non-developed TWG-SMR members (Jordan, Indonesia, Australia, Iran, Pakistan, India) would prepare the 1st draft of the RD by the next 6 months.
2. Consultancy Meeting in 2018: The other IAEA member countries would be familiar with the SMR and the RD. In this meeting the 1st draft of the developed specific RDs would present to the participants and ask them to develop their documents by the next 6 months.
3. Technical Meeting in 2019: all the developed RDs would be presented and the 1st draft of the generic RD would be developed by the TWG-SMR Panel A members, during the next 6 months.
4. IAEA: in parallel to activities 1-3, IAEA staff try to provide the TWG-SMR Panel A members with the associated criteria.



Thanks.

Extra slides

What is an SMR?

IAEA

- **Small** and **Medium Reactors**
- Output <700MWe
- Modular
- Share “Balance of Plant”

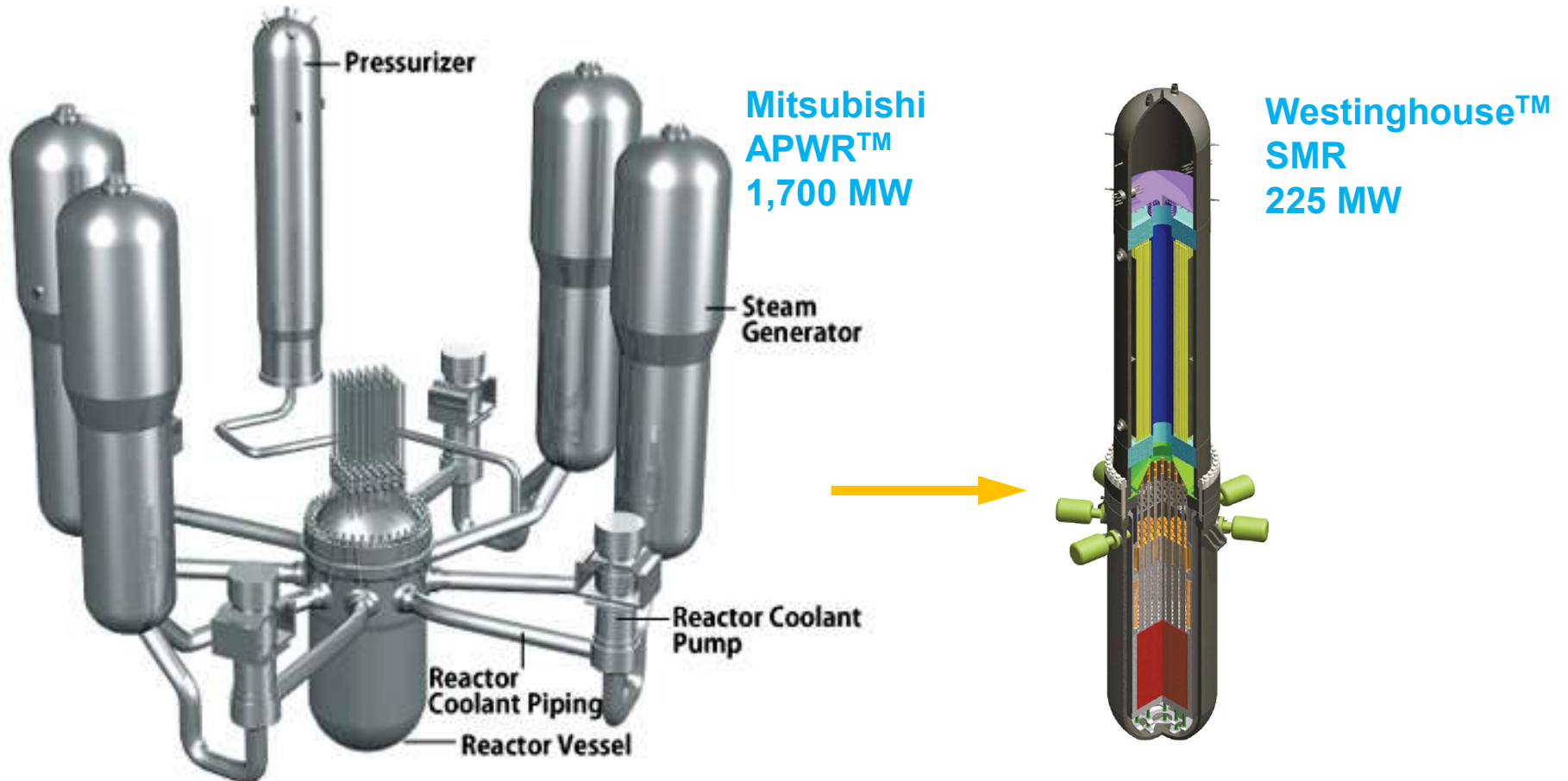
The Market

- **Small Modular Reactors**
- Output <300MWe
- Factory fabricated
- Transportable: rail or road
- Grouped to form larger plants

Reactor vendors



SMRs: miniaturise & mass produce



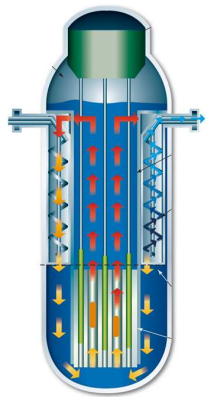
Graphics:
Mitsubishi Heavy Industries &
Westinghouse SMR

SMRs - iPWRs

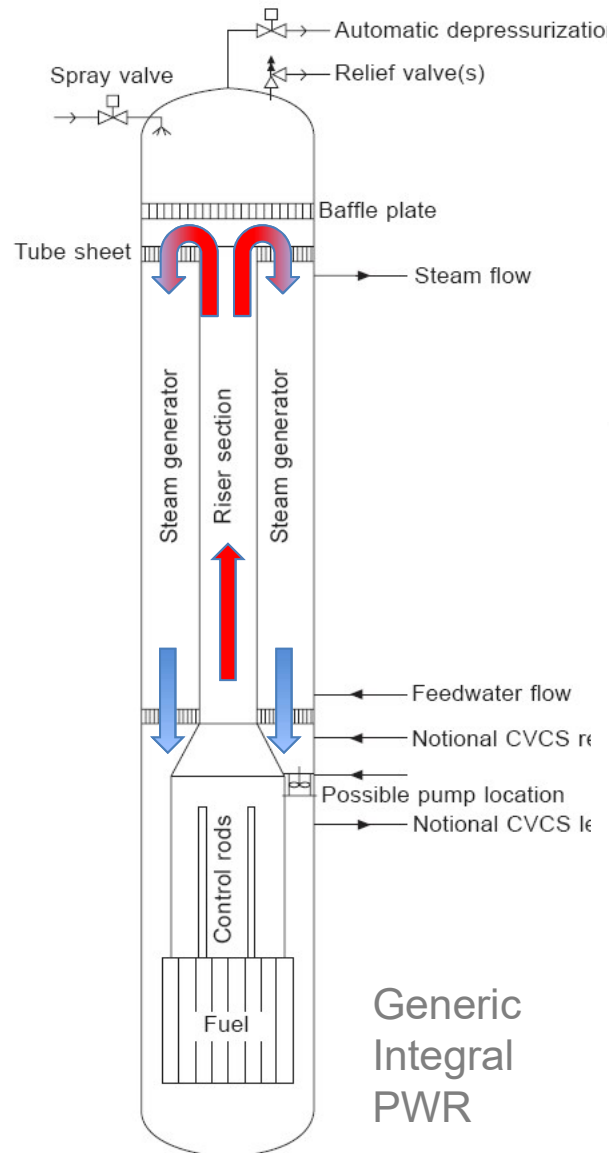
Natural Convection
(no pumps, limit ~70 MW)



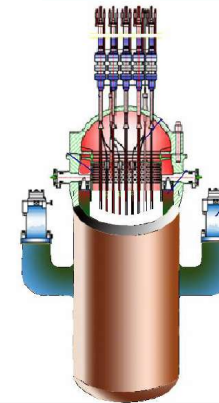
NuScale
50 MW



CAREM
32 MW



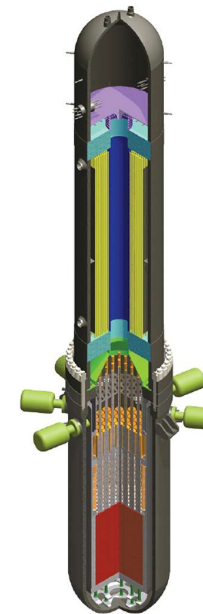
Forced Convection
(pumps)



ACP-100
100 MW



mPower
180 MW



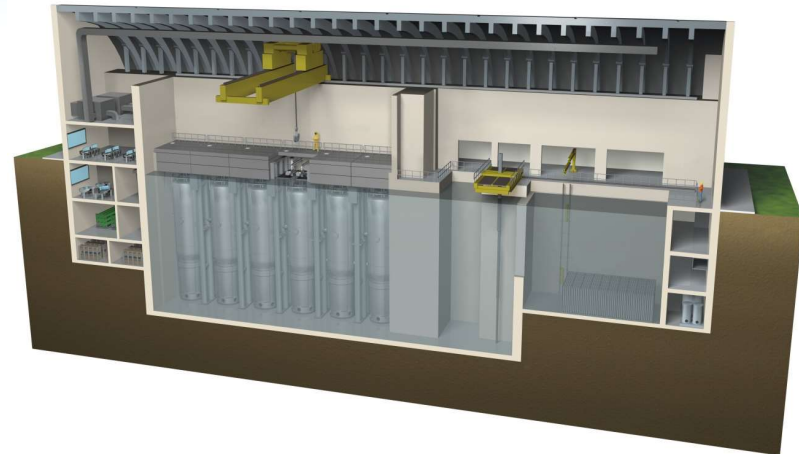
Westinghouse
225 MW

Source: Belles (2015)

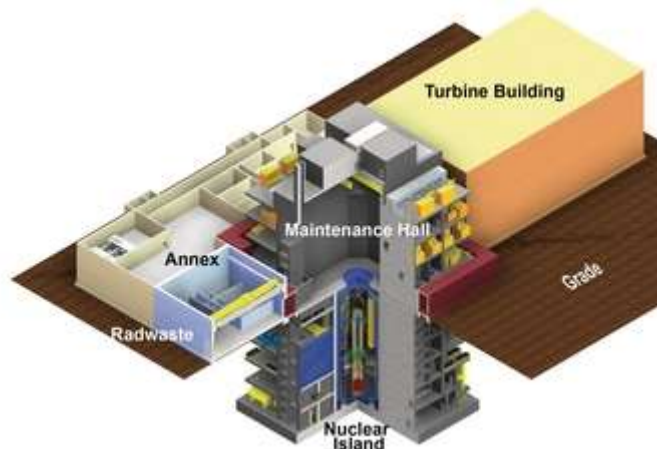
Passive Safety



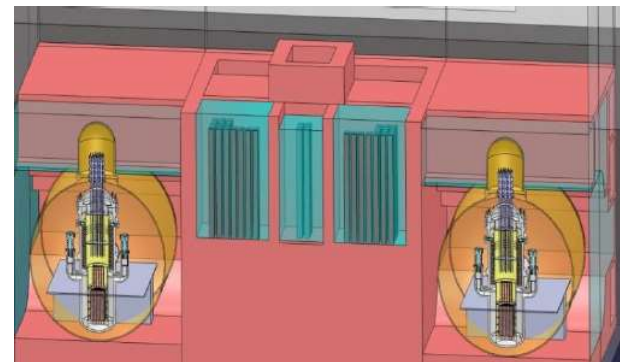
mPower



NuScale



Westinghouse SMR

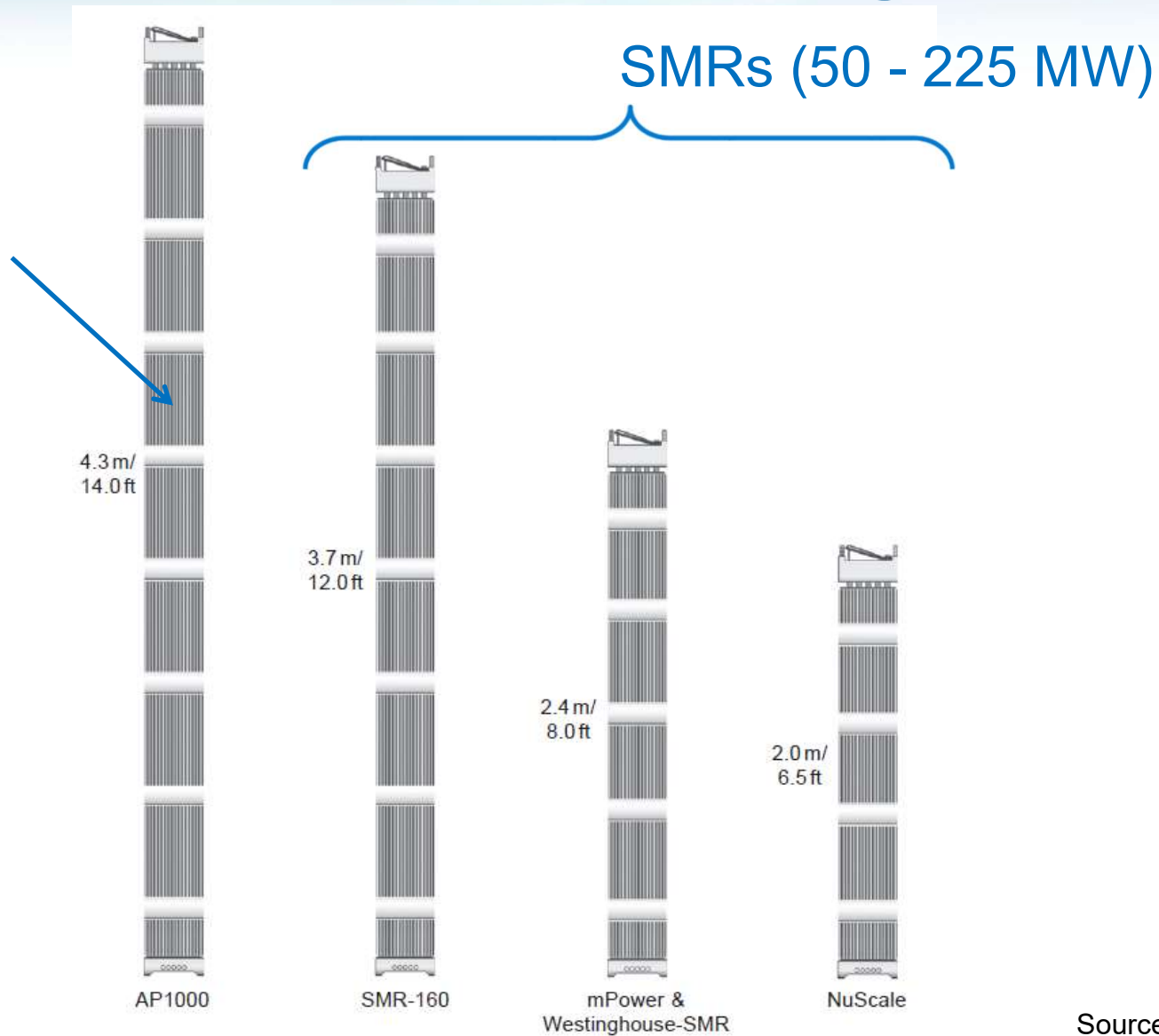


ACP-100

Sources: CNNC, mPower, NuScale

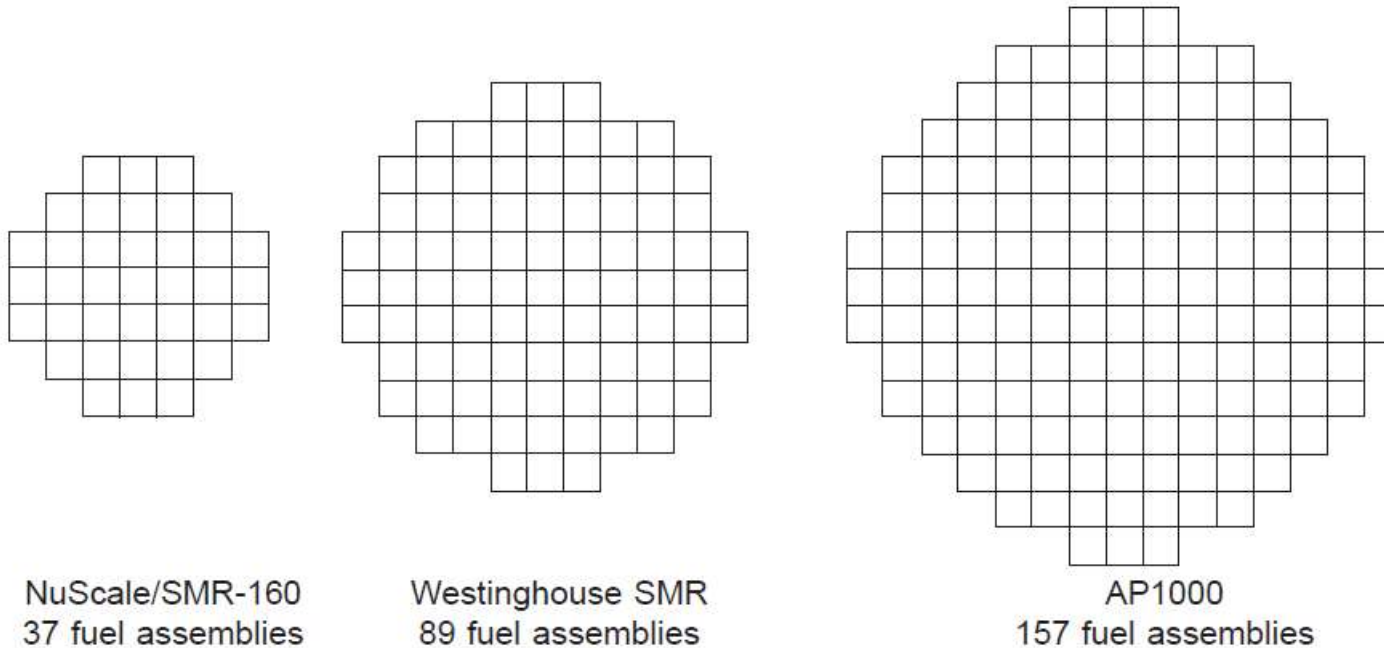
Smaller fuel loading

AP-1000
(1,100 MW)



Source: Worrall (2015)

Smaller core size

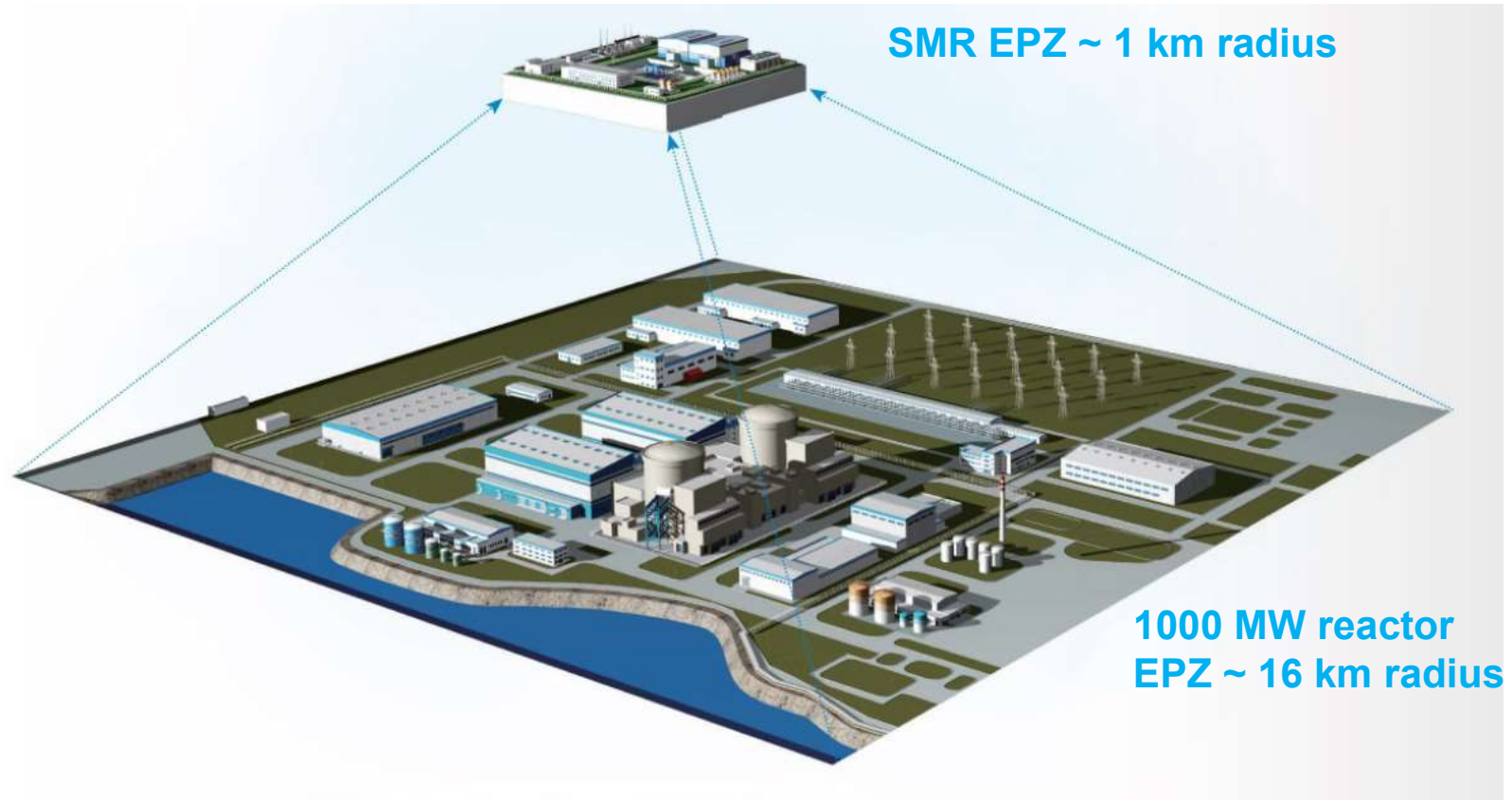


NuScale = 50 MWe

Westinghouse SMR = 225 MWe

Westinghouse AP-1000 = 1,100 MWe

Very small emergency planning zones



Framework for Reactor Design

Coolant

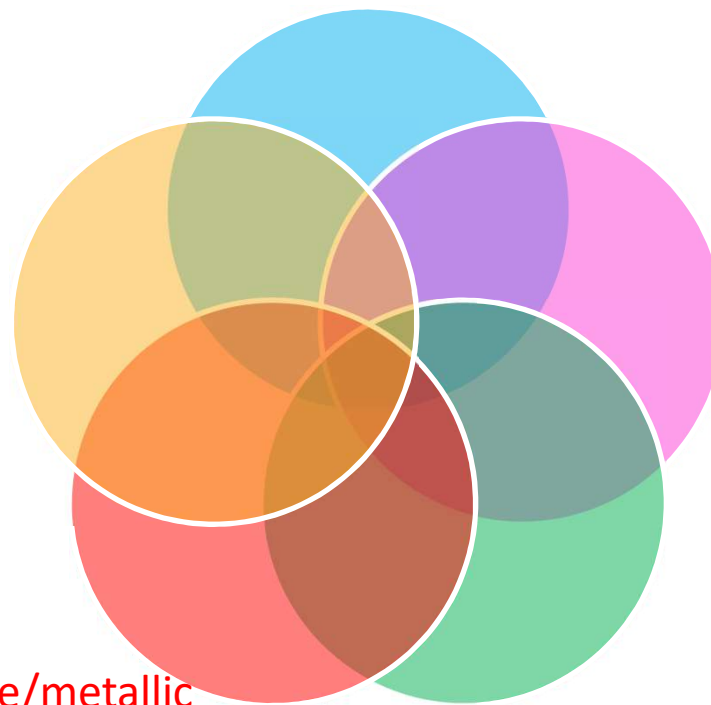
- Density & viscosity
- Thermal conductivity & heat capacity.
- Heat Transfer characteristics
- Neutron capture

Materials

- Neutron capture
- Heat transfer
- Corrosion rate
- dpa damage

Fuel selection

- Enrichment
- UO/MOX/nitride/metallic
- Reprocessing option
- irradiation damage



Neutronics

- Burn-up
- Shielding
- Core power cosine
- Fuel shuffling

Safety Analysis

- Containment
- Cover gas
- pool (integral) design
- Passive safety system
- intermediate loop
- core melt re-criticality

The Bigger Picture

