# INTRODUCTION TO SMR'S

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20 April 2018

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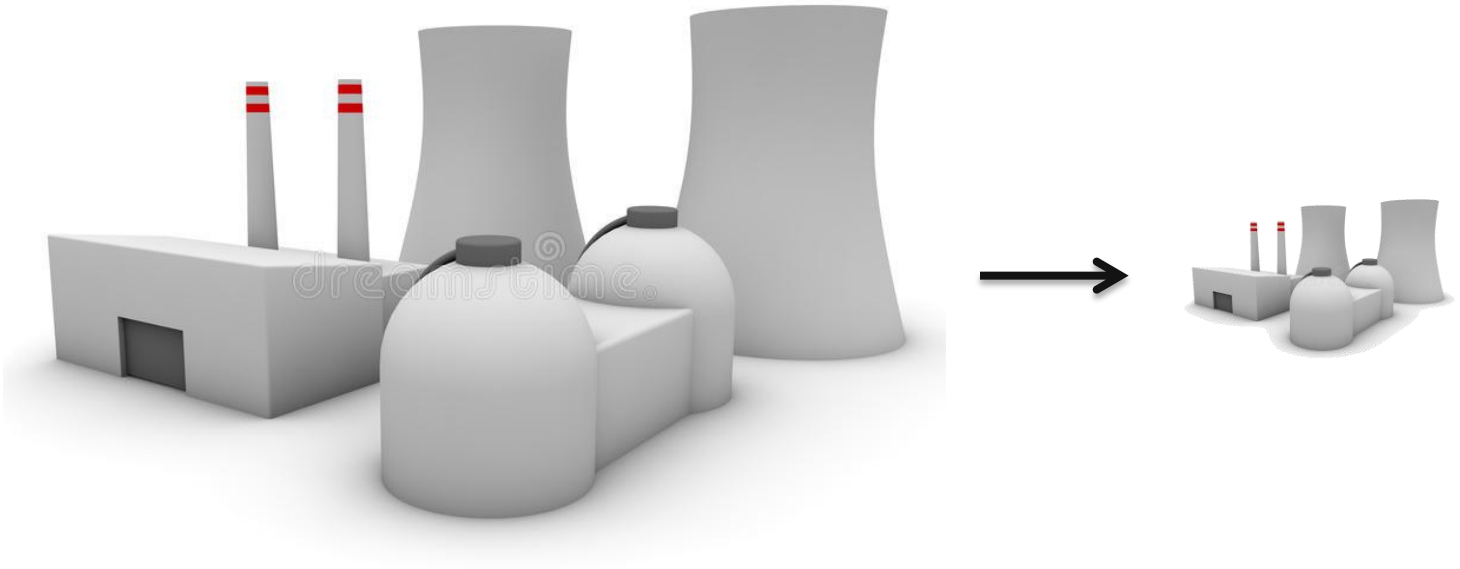


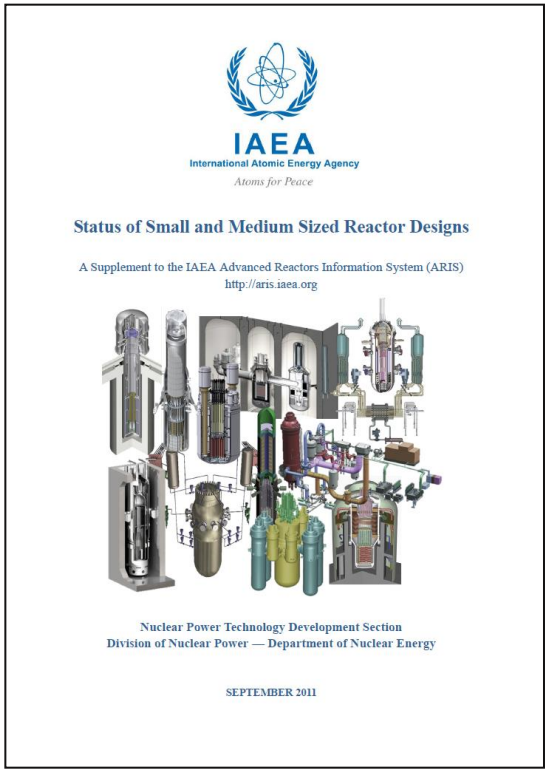
# WHAT IS AN SMR?

# WHAT IS AN SMR?

## DEFINITION: IAEA

IAEA

- Small to Medium sized Reactors
- < 700 MWe or even < 300 MWe
- Small grids
- Low rates of increase in demand
- (Developing countries with developing grids)
- Multi-module offers operation flexibility
- Cogeneration
- Alternative fuel management

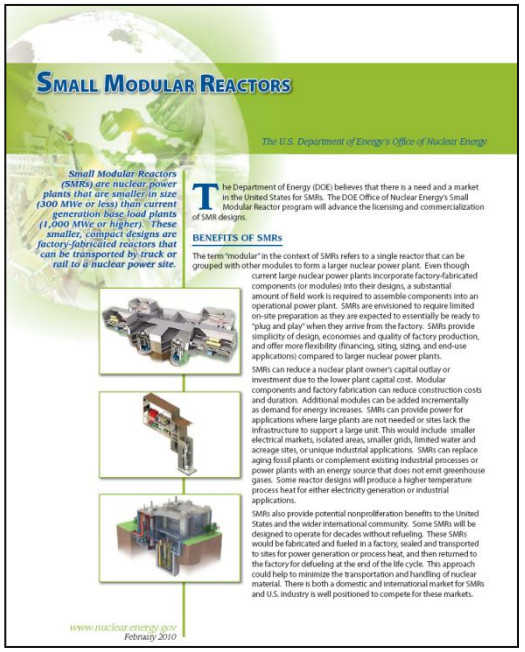



IAEA, 2011

# WHAT IS AN SMR?

## DEFINITION: US DOE

- US DOE
  - Small Modular Reactor
  - < 300 MWe
  - ‘Plug and play’
  - Flexibility (financing, siting, sizing, end use)
  - Phased investment when modular constructed
  - Isolated areas
  - Proliferation resistant by cassette fuelling




US DOE, 2010

# WHAT IS AN SMR?

## REACTOR GENERATIONS

Gen I

Gen II

Gen III

Gen III+

Gen IV

1950 1970 1990 2010 2030 2050 2070 2090

SMRs

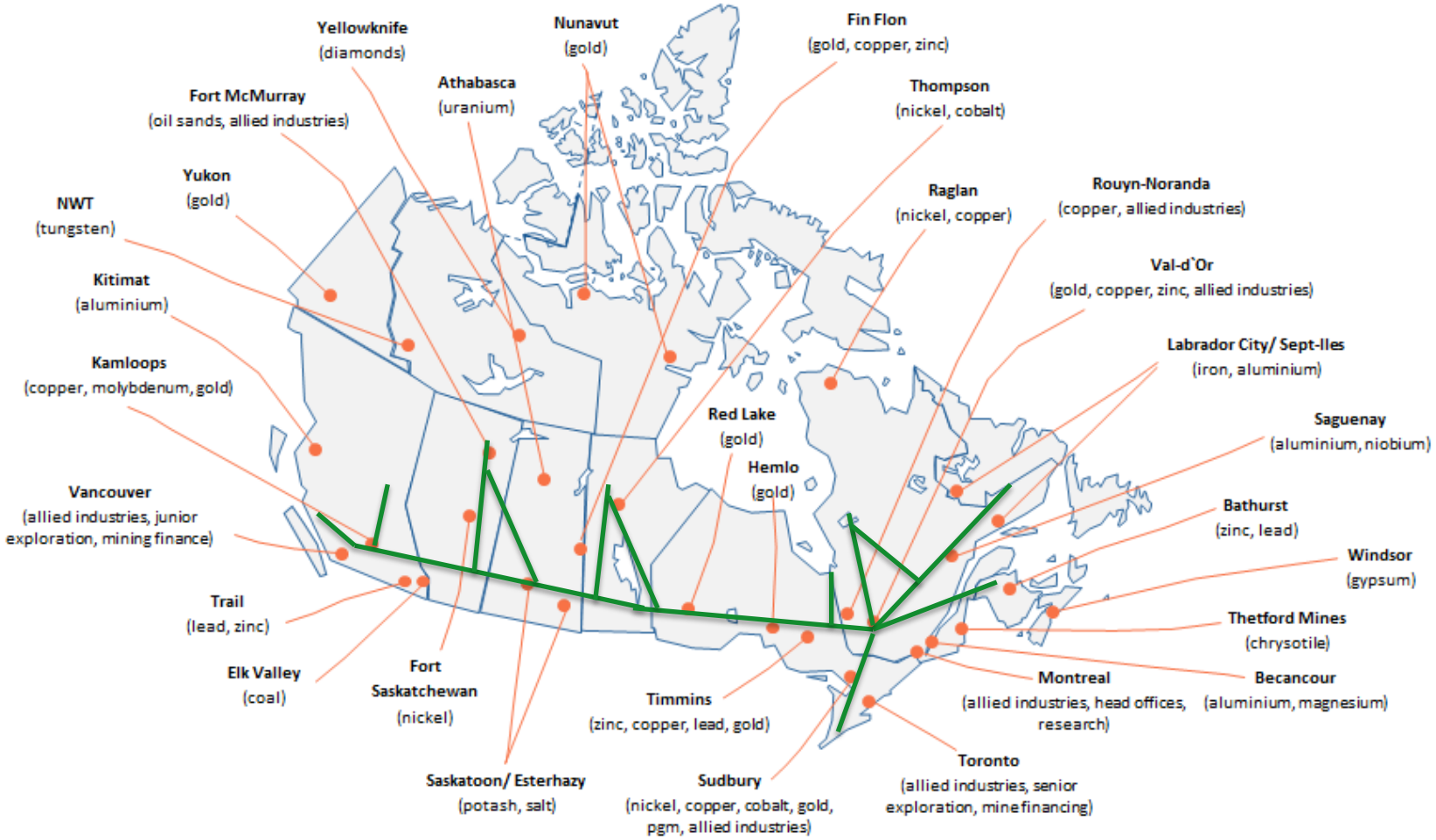
# WHY SMR'S?

# WHY SMR?

- Small grids / off-grid locations
  - Developing countries
  - Islands
  - Arctic/desolate regions
- Low rates of increase in demand
- Reduction of investment risk
  - Small size
  - Phased investment (per unit)
- Combined heat and power (cogeneration)
  - Linked to industry end-user

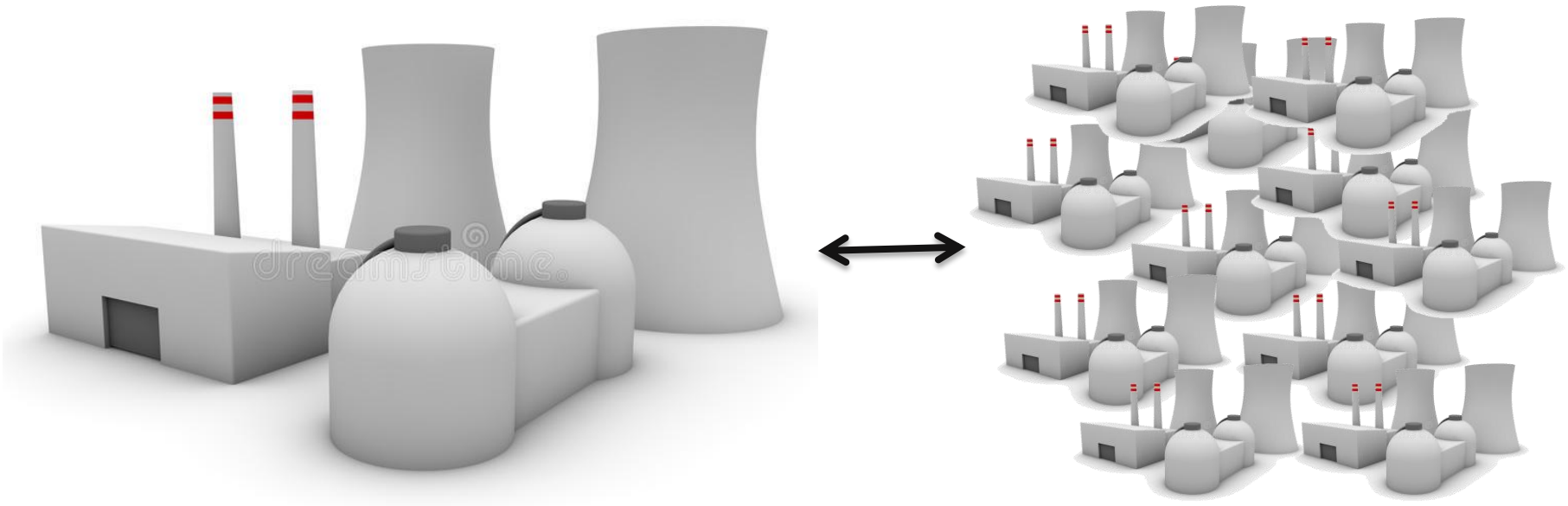
# WHY SMR?

## MINING VS POWER GRID (CANADA)



# WHY SMR?

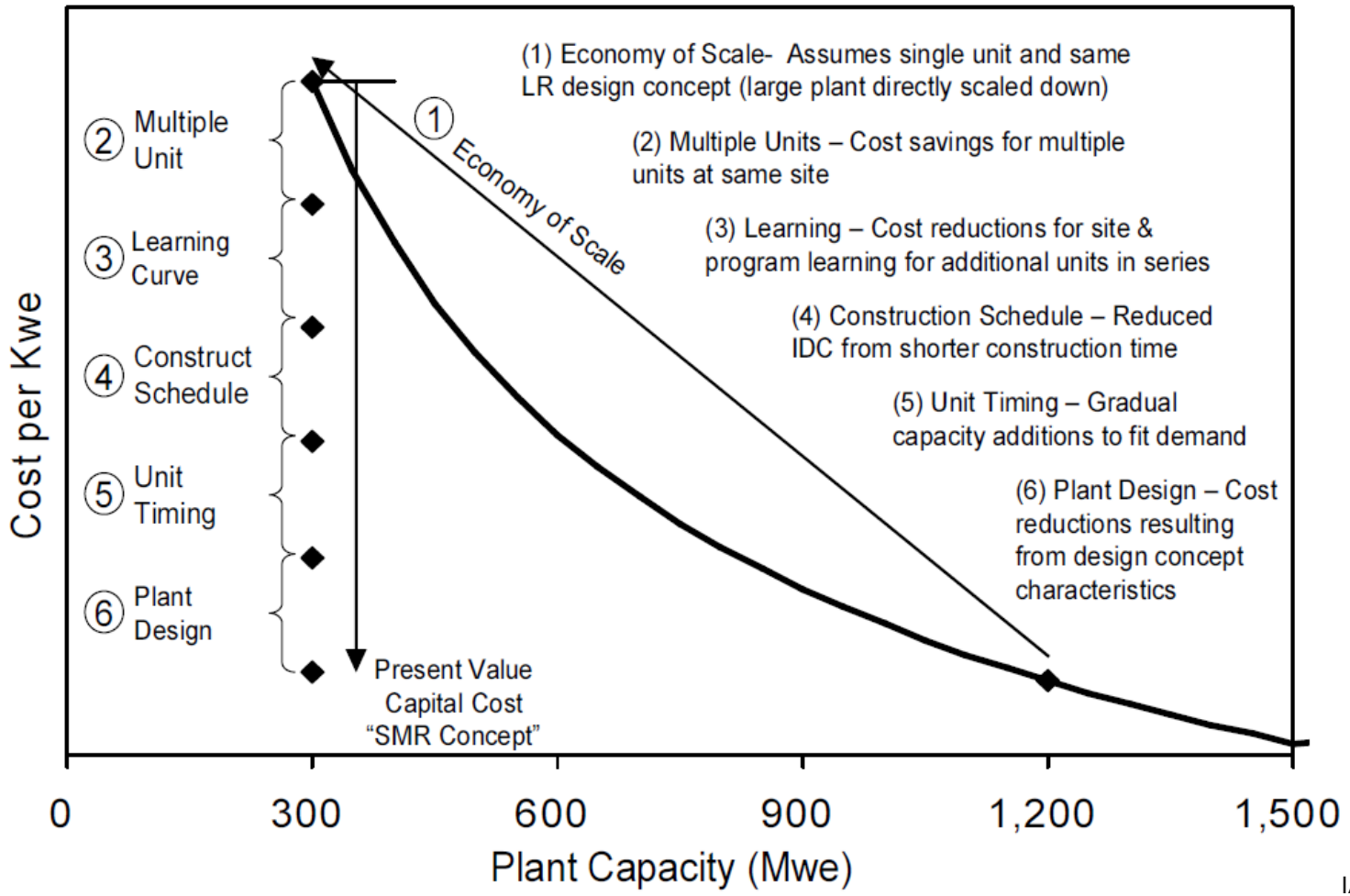
## ECONOMICS OF NUMBERS VS SCALE



IAEA, 2013

# WHY SMR?

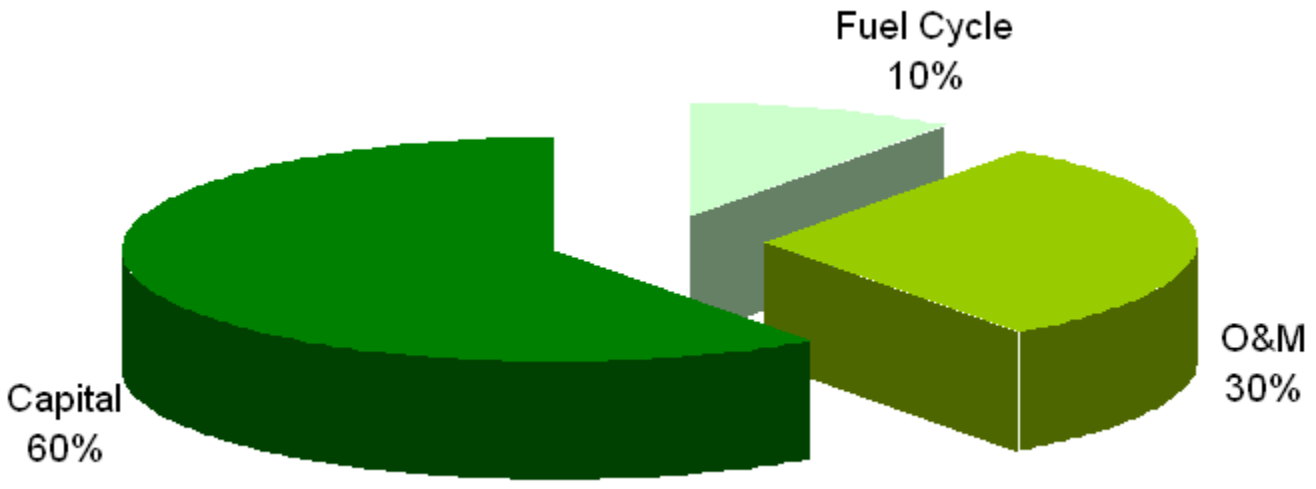
## ECONOMICS OF NUMBERS VS SCALE



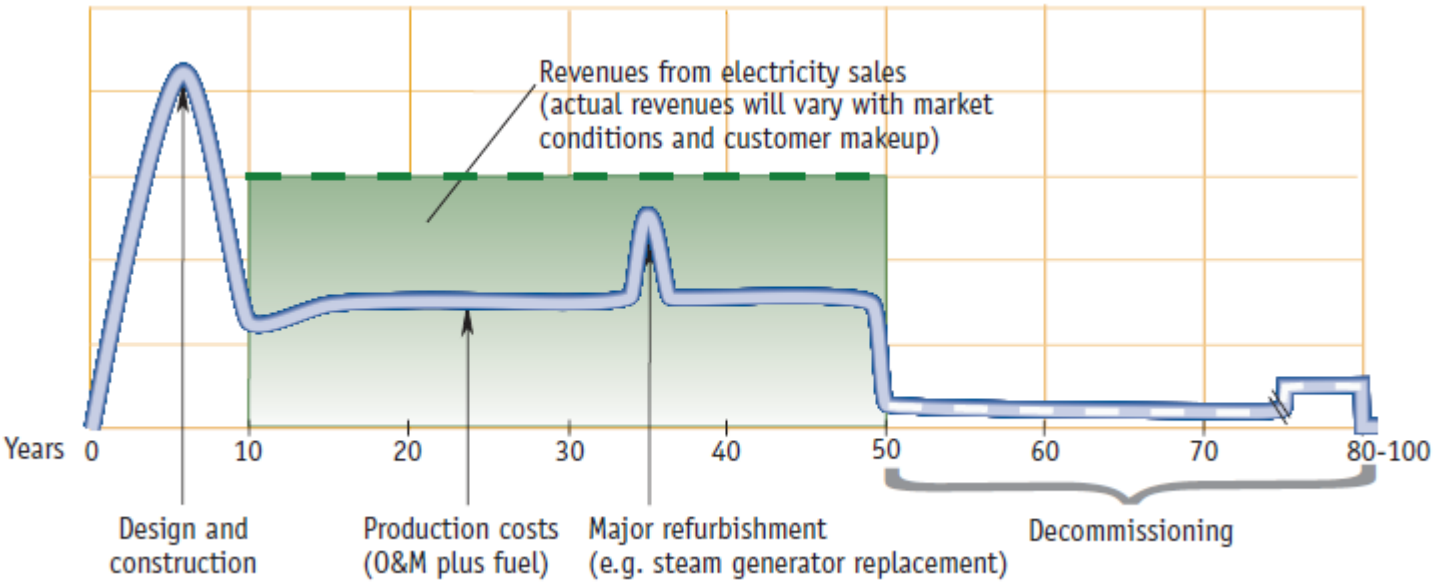

IAEA, 2013

# WHY SMR?
## COST DISTRIBUTION IN NUCLEAR

- Nuclear: Capital costs by far most important
  - Reduction in capital cost = reduction in electricity generation cost



# WHY SMR?
## CASH FLOW

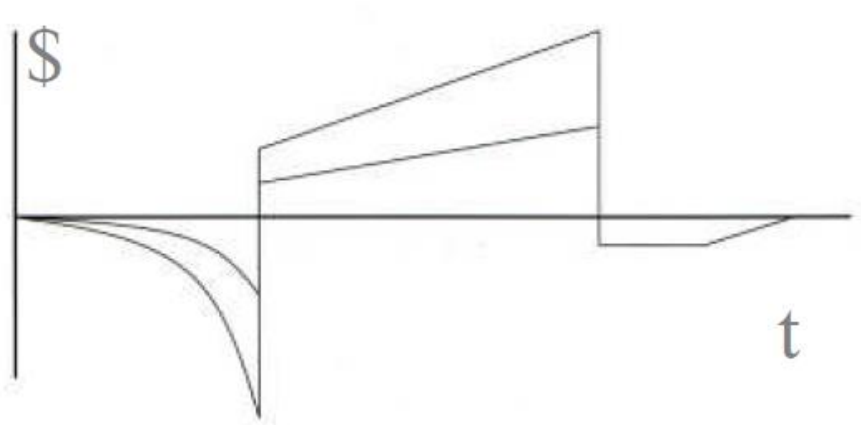



OECD, 2005

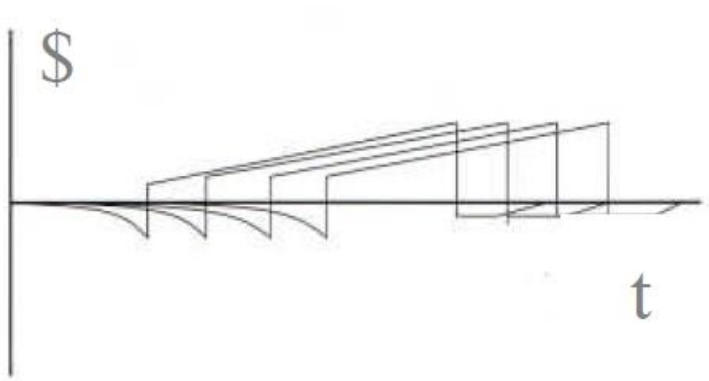
# WHY SMR?

## INVESTMENT RISK REDUCTION

Cash flow large reactor



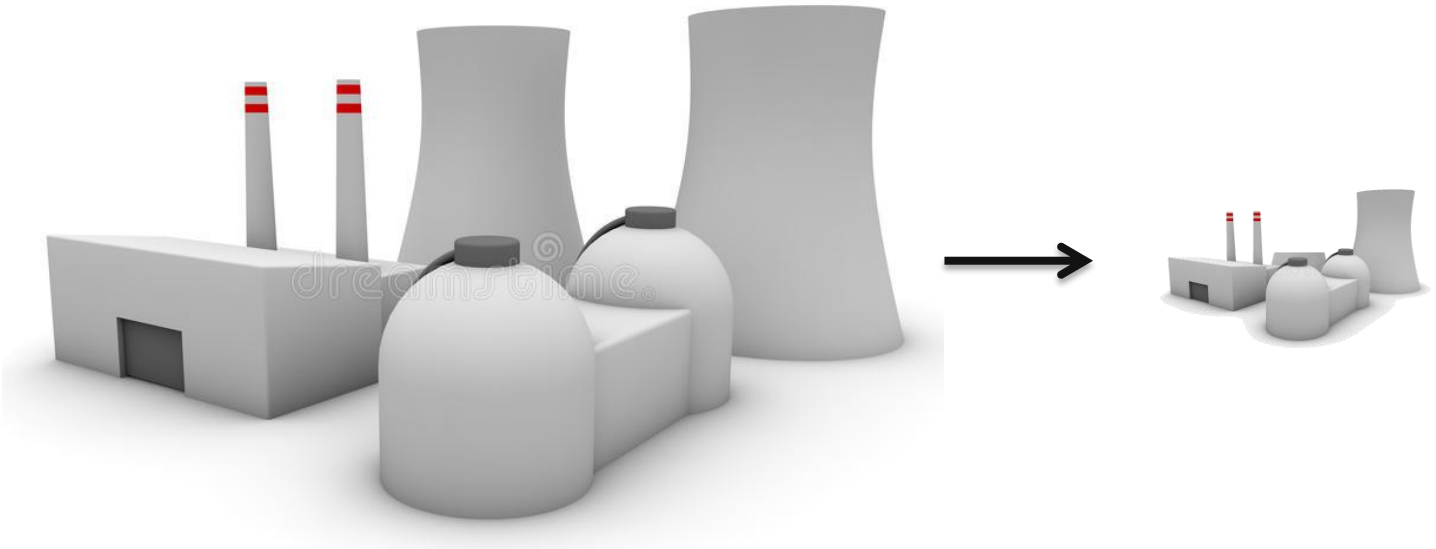

Cash flow multiple SMR's



# WHY SMR?
## DESIGN SIMPLIFICATION

1000 MWe / 3000 MWth

200 MWe / 600 MWth



- Thermal power is an important factor in design of safety systems
- Decay heat 10% ↓ of nominal thermal power

# WHY SMR?

## BENEFITS & DRAWBACKS

**Technology Issues**
- Shorter construction period (modularization)
- Potential for enhanced safety and reliability
- Design simplicity
- Suitability for non-electric application (desalination, etc.).
- Replacement for aging fossil plants, reducing GHG emissions

**Non-Techno Issues**
- Fitness for smaller electricity grids
- Options to match demand growth by incremental capacity increase
- Site flexibility
- Reduced emergency planning zone
- Lower upfront capital cost (better affordability)
- Easier financing scheme

**Technology Issues**
- Licensability (FOAK designs)
- Non-LWR technologies
- Operability and Maintainability
- Staffing for multi-module plant; Human factor engineering;
- Supply Chain for multi-modules
- Advanced R&D need

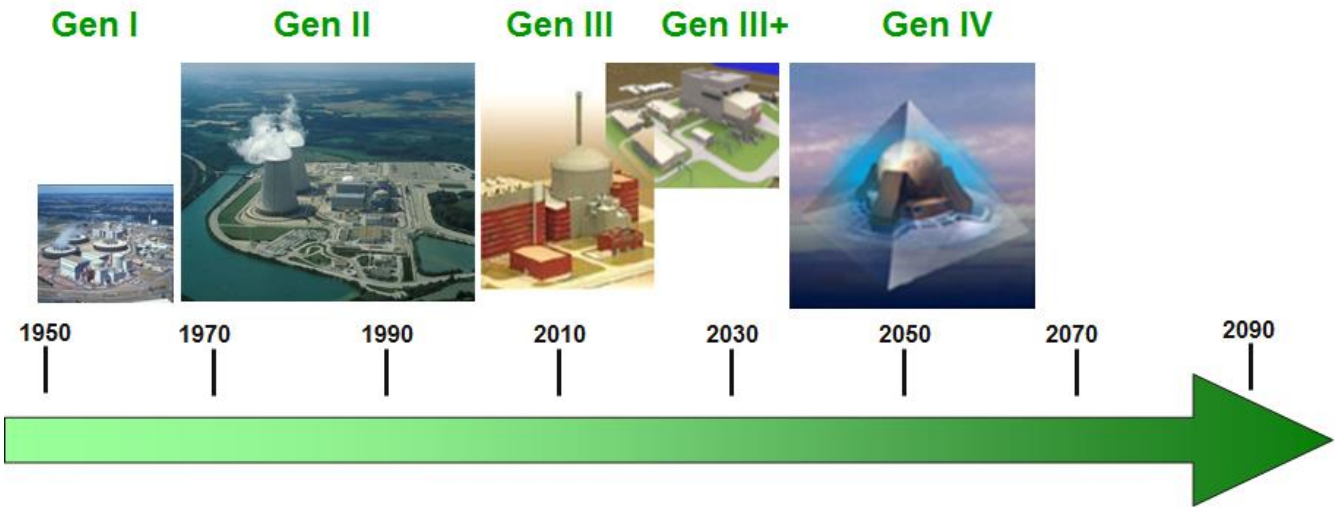
**Non-Techno Issues**
- Economic competitiveness
- Plant cost estimate
- Regulatory infrastructure
- Availability of design for newcomers
- Physical Security
- Post Fukushima action items on institutional issues and public acceptance

# WHICH SMR'S

# WHICH SMR'S?

## DIFFERENT TYPES

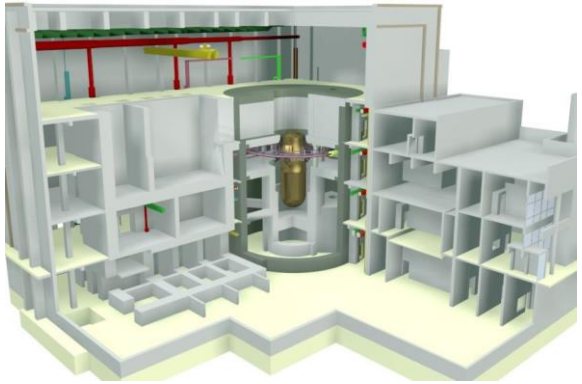
- SMR's are technology independent:
  - Light Water Reactor
    - Mostly PWR, often integral
  - High Temperature Reactor
    - Very suitable for cogeneration
  - Molten Salt Reactor
    - Many start-ups
  - Sodium Fast Reactor
    - Scaled down versions of large SFR
  - Lead Fast Reactor
    - Some dedicated designs
  - Gas Fast Reactor
    - One special design



# WHICH SMR'S?

## LWR: CAREM

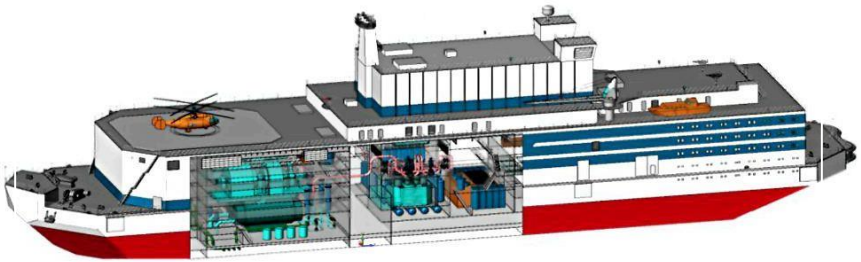
- **Central Argentina de Elementos Modulares**
- Vendor: CNEA / INVAP
- 27 MWe
- Integral primary system (steam generators in vessel)
- Electricity & desalination
- Construction of prototype in Formosa started in 2014. Operation start planned in 2019.
- Prototype to be followed by larger versions (100-200 MWe)
- Under consideration for desalination in Saudi Arabia



# WHICH SMR'S?

## LWR: KLT-40S

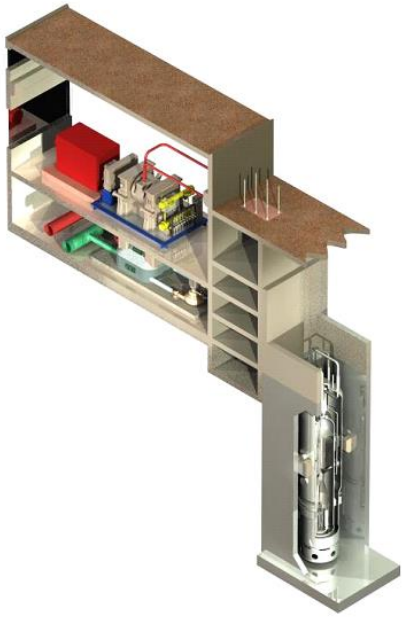
- Vendor: OKBM
- 35-70 Mwe
- Refuelling 3-4 yr
- Floating nuclear plant
- Twin reactor plant proven for ice-breaker propulsion
- First plant 'Akademik Lomonosov' under construction for Pevek in the Chukota region (electricity & heat supply for naval base) as replacement of 35 MWe thermal plant by 2020. Start planned 2019.

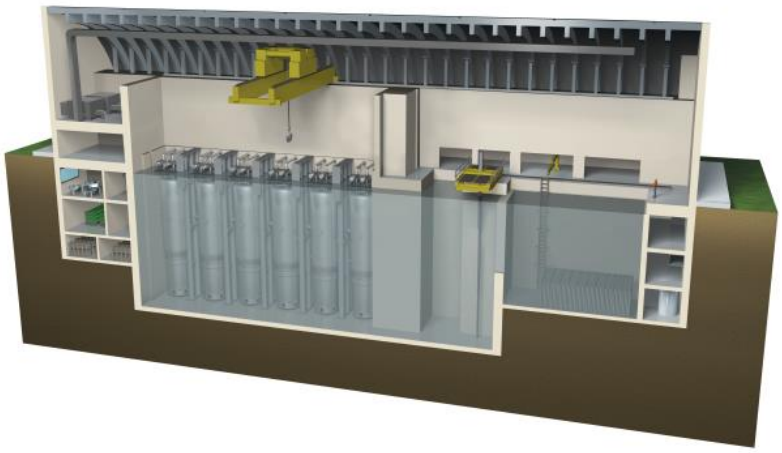


# WHICH SMR'S?

## LWR: NUSCALE

- Vendor: NuScale Power
- 160 MWth / 50 MWe
- Integral primary system
- <12 reactors in shared pool
- Refuelling 2 yr
- Natural circulation
- Electrically heated prototype

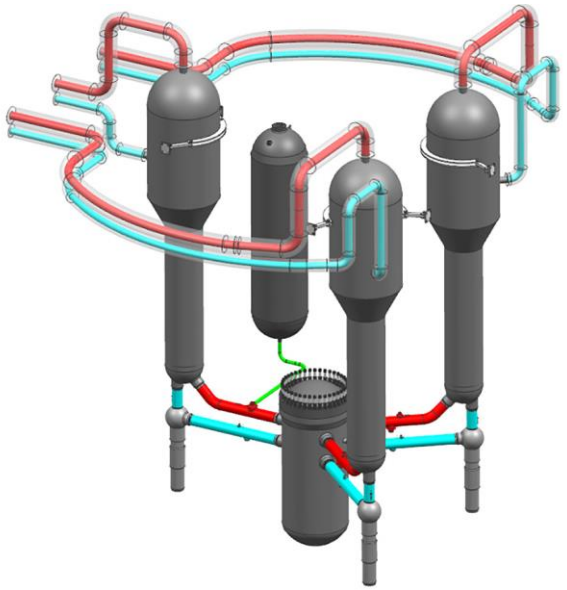




# WHICH SMR'S?

## LWR: UK SMR

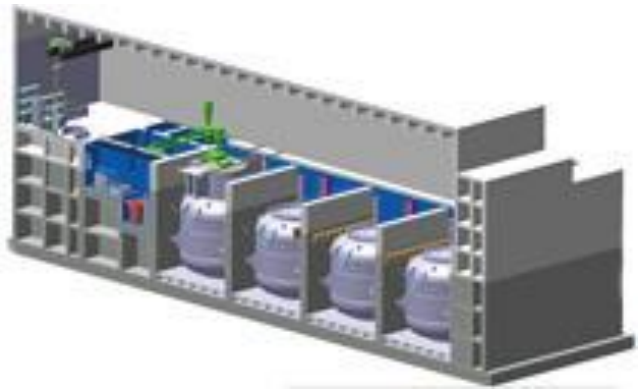
- **UK SMR**
  - Vendor: Rolls-Royce
  - 400-450 Mwe
  - 3-loop PWR
  - Optimise LCOE vs capital costs
  - Operation start 2030

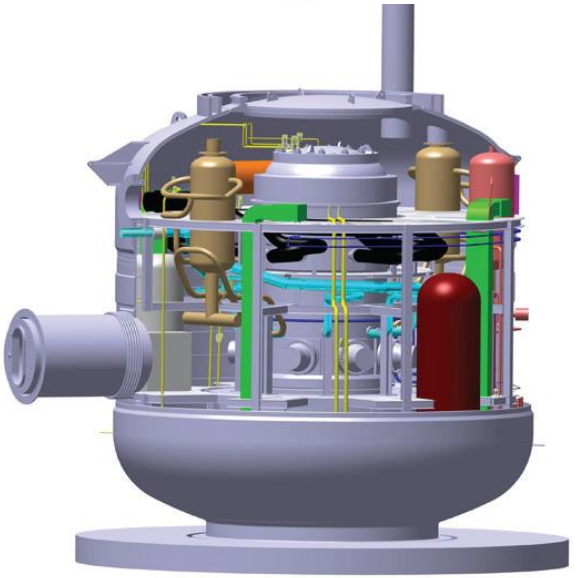


# WHICH SMR'S?

## LWR: FRANCE

- **French SMR**
  - Vendor: Technicatom / Naval Group / CEA / EDF
  - 170 MWe
  - Integral PWR
  - Metallic containment shell submerged in water pool
  - 2-4 units per site
  - Grace time: 1 week

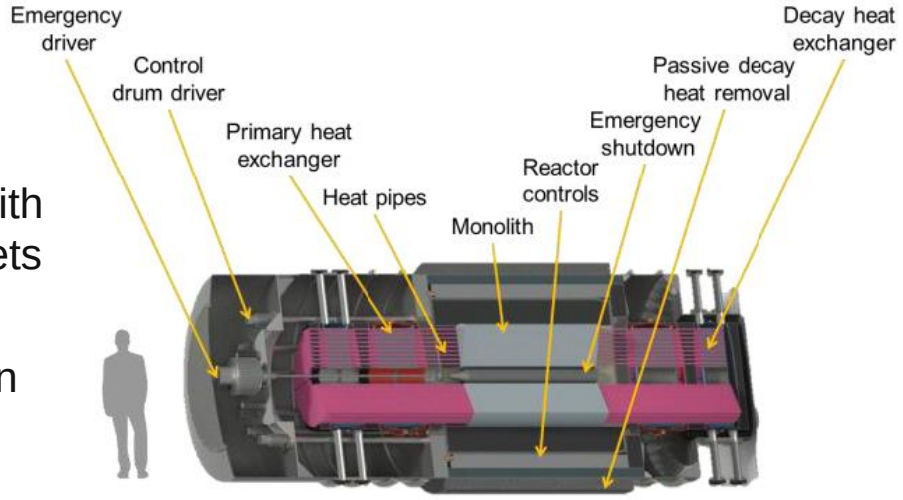




# WHICH SMR'S?

## LWR: EVINCI

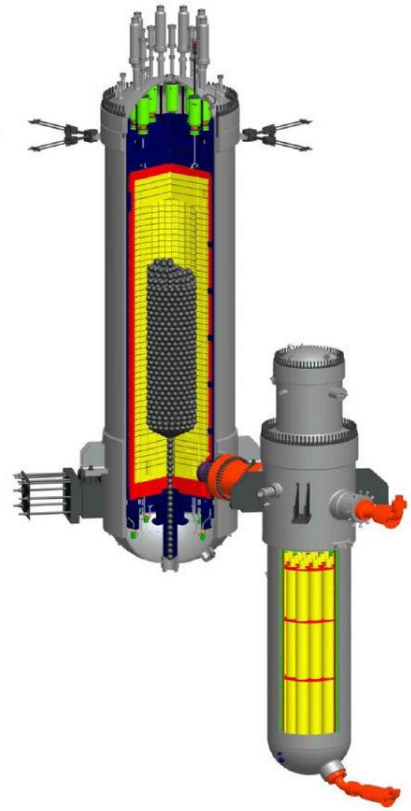
- **eVinci microreactor**
  - Vendor: Westinghouse
  - 0.2 - 25 MWe electricity and heat
  - Unique core design, steel monolith with channels for heat pipes and fuel pellets
  - Refuelling 10 yr
  - Qualification for commercial operation planned by 2024
  - Market: Off-grid customers




# WHICH SMR'S?

## HTR: HTR-PM

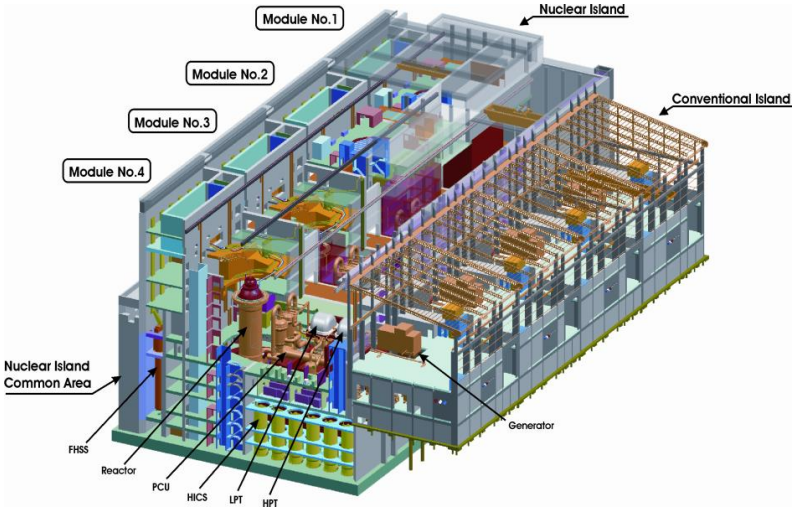
- **HTR-Pebble Modular**
  - Vendor: CNECC, China
  - 500 MWth / 200 MWe
  - Based on German HTR-Modul Design
  - Steam cycle (indirect)
  - ~500 000 Pebbles
  - Modular
  - Start operation planned 2018

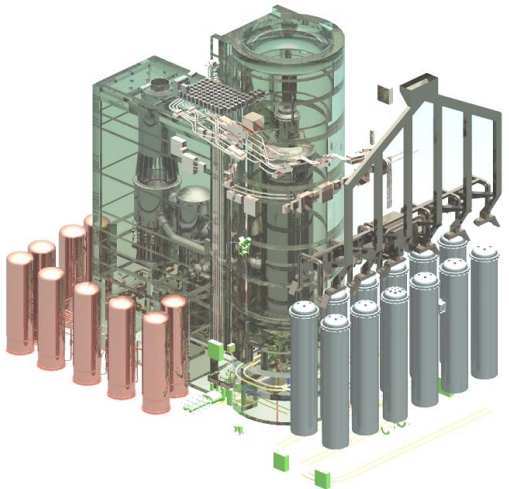


# WHICH SMR'S?

## HTR: PBMR

- **Pebble Bed Modular Reactor**
  - Vendor: PBMR, South-Africa
  - 165 MWe
  - Pebbles
  - Based on German HTR-Modul Design
  - Brayton cycle (direct)
  - Project abandonned in 2010

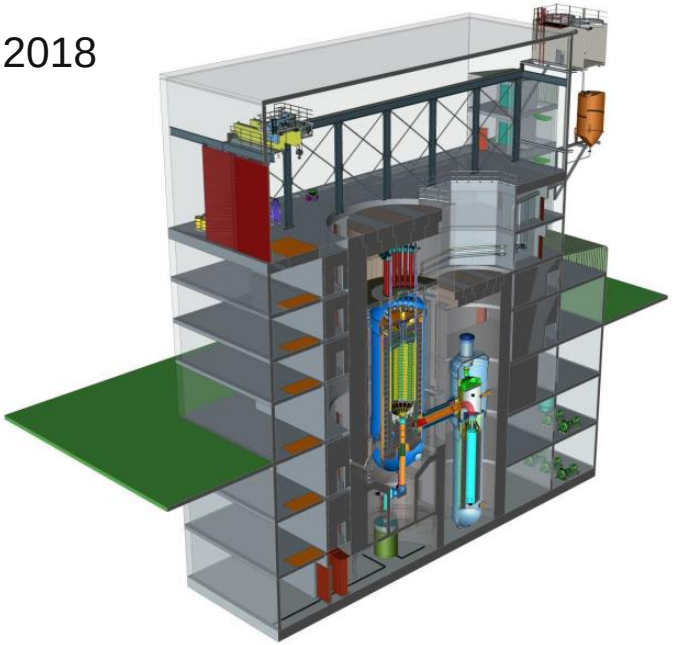


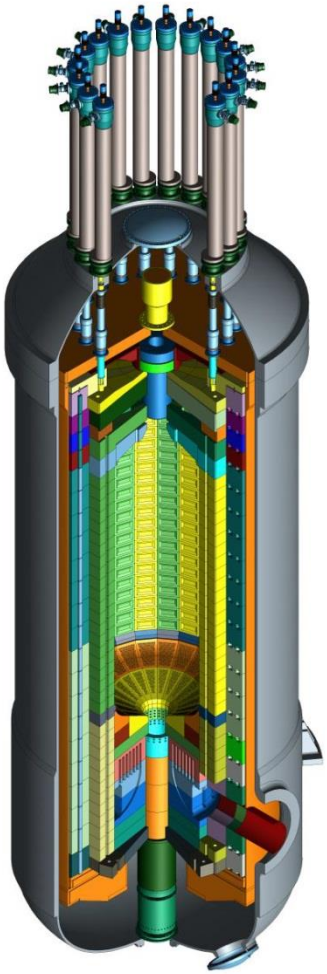



# WHICH SMR'S?

## HTR: HTMR

- **High Temperature Modular Reactor**
  - HTMR Ltd
  - 35 MWe / 100 MWth
  - 750°C
  - Steam cycle
  - Flexible fuel (U, Pu, Th)
  - Conceptual design planned for 2018

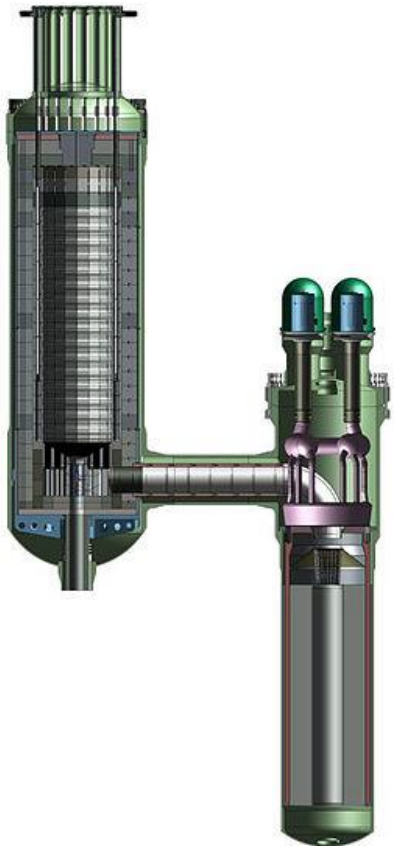


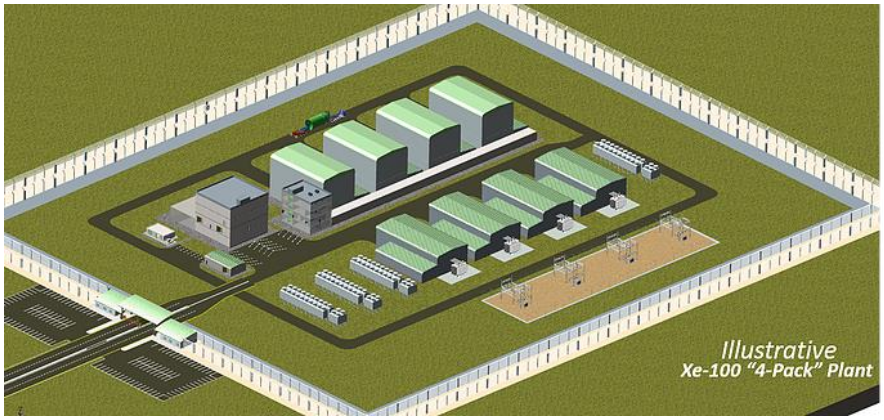


# WHICH SMR'S?

## HTR: XE-100

- **X-energy 100**
  - X-Energy, USA
  - 200 MWth / 76 MWe
  - ~220 000 Pebbles
  - Steam production at 540°C
  - Underground building
  - Conceptual design started in 2017
  - MoU on potential in Jordan

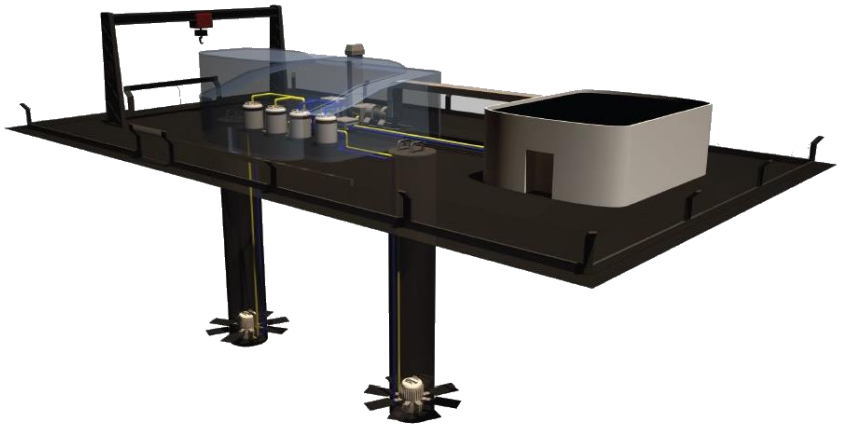


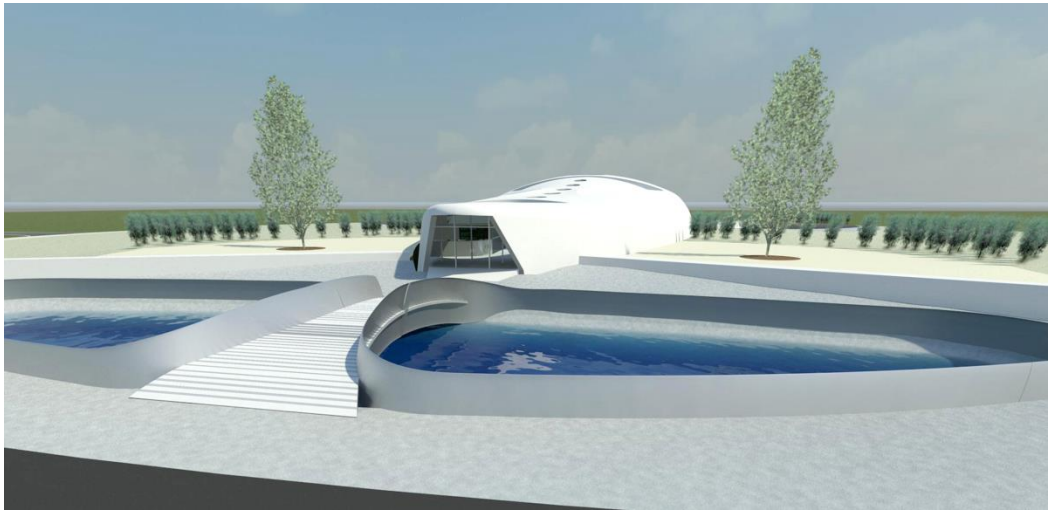


# WHICH SMR'S?

## HTR: STARCORE

- **StarCore**
  - StarCore Power LLC
  - 36 MWth / 20 MWe
  - 5 yr refuelling
  - Underground building
  - Fully automated

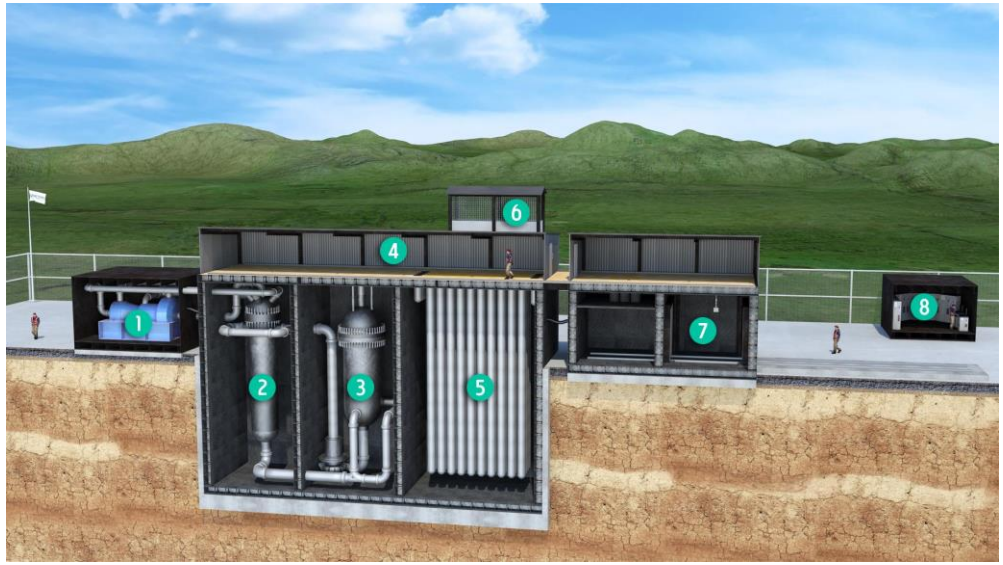




# WHICH SMR'S?

## HTR: U-BATTERY

- **U-Battery**
  - U-Battery
  - 10 MWth / <4 MWe
  - 750°C process heat
  - Industrial power units
  - Off-grid locations
  - Back-up for large plant emergency diesels
  - Demonstration by 2026



# WHICH SMR'S?

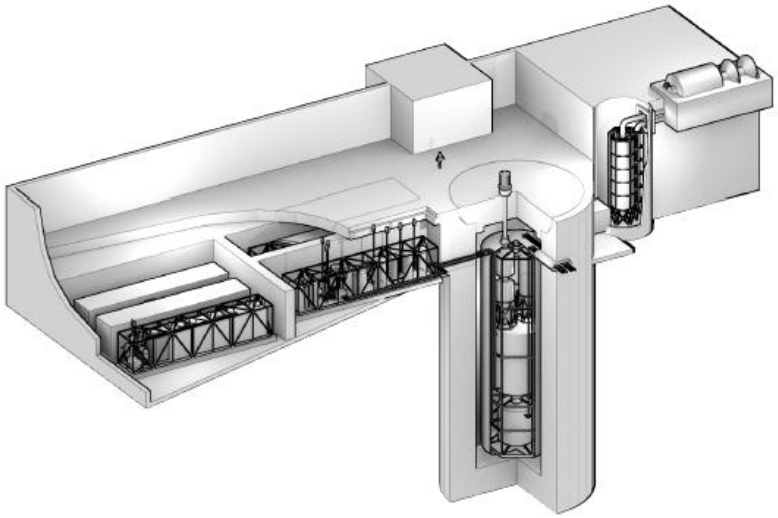
## MSR: IMSR

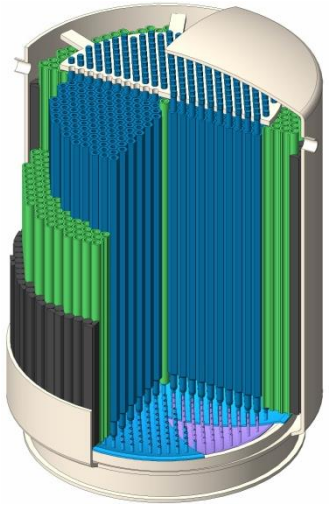
- **Integral Molten Salt Reactor**
  - Terrestrial Energy
  - 400 MWth / 192 MWe
  - Sealed and replaceable core
  - Refueling 7 yr
  - Successfully concluded first phase of Canadian regulatory program

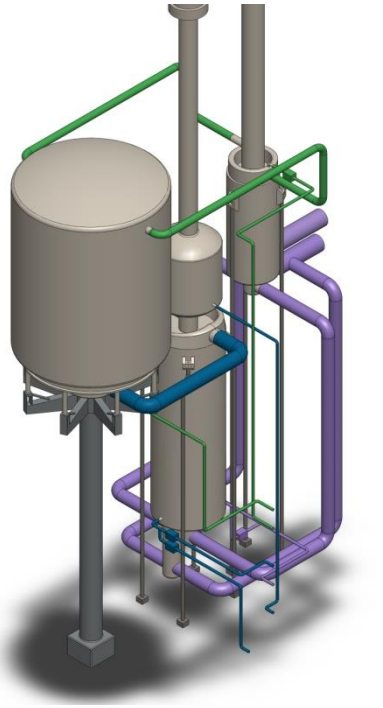
# WHICH SMR'S?

## MSR: LFTR

- **Liquid-Fluoride Thorium Reactor**
  - Design: Flibe Energy
  - FLiBe salts
  - Graphite Moderator
  - 600 MWth / 250 MWe
  - Fuel: Th
  - Breeder



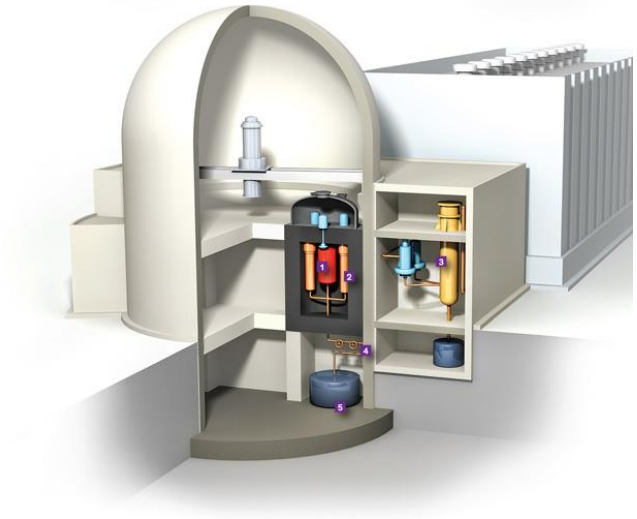


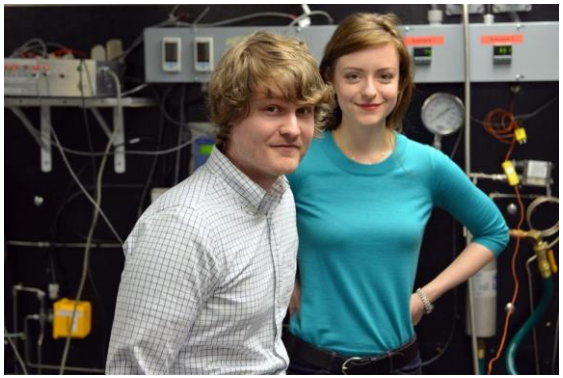


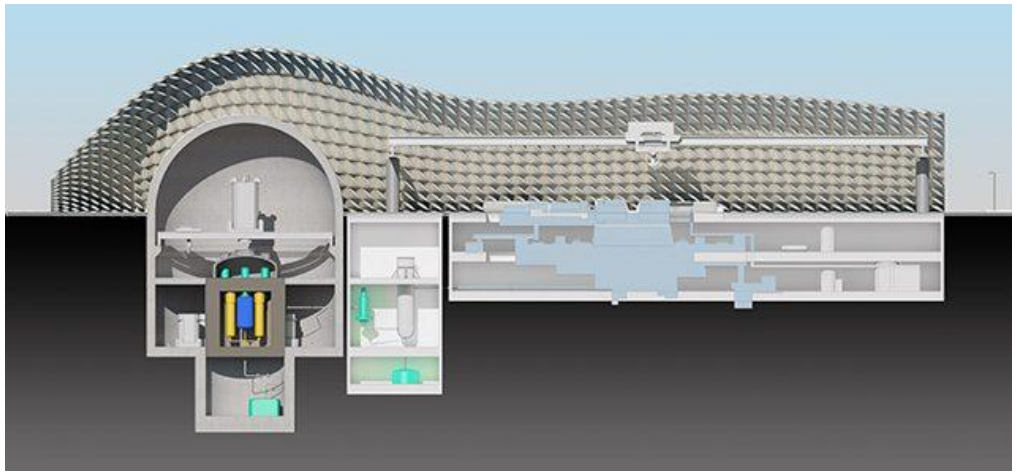
# WHICH SMR'S?

## MSR: TAP

- **TransAtomic Power**
  - Design: Transatomic Power
  - Li-F based salt
  - Moderator: Zirconium Hydride
  - 1250 MWth / 520 MWe
  - Core outlet: 650°C
  - Efficiency: 44%
  - Fuel: Uranium
  - 'Walkaway safe'



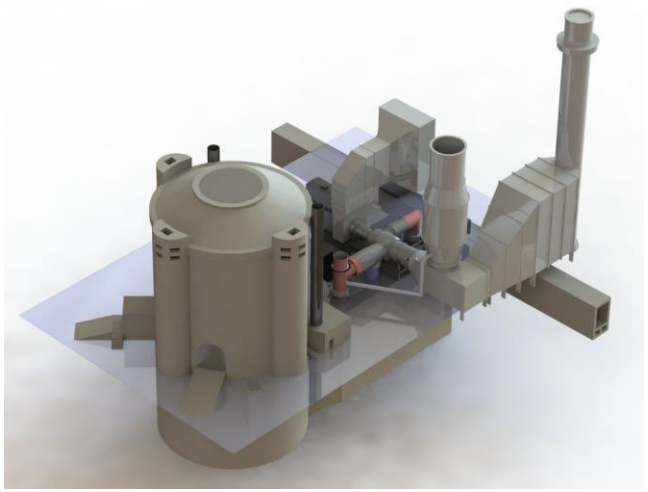


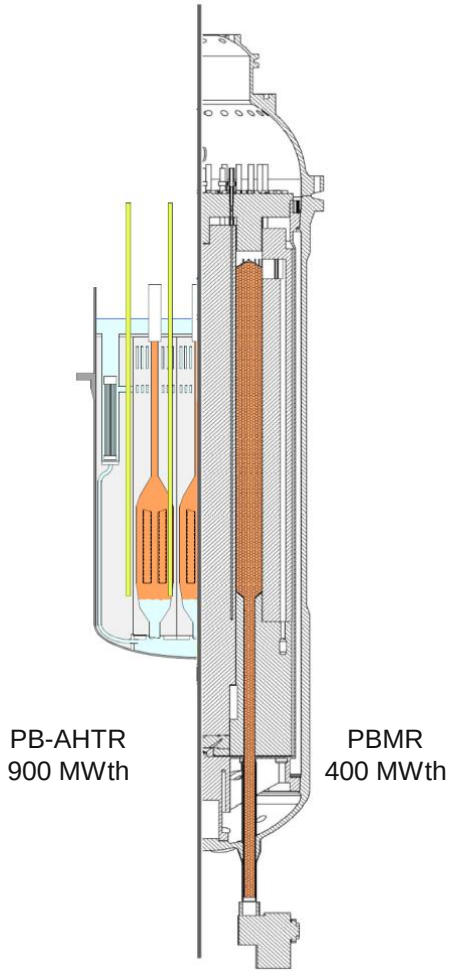


# WHICH SMR'S?

## MSR: MK1-PB FHR

- **Mark-1 Pebble Bed Fluoride salt-cooled High temperature Reactor**
  - Designs: ORNL / MIT / University of California
  - 236 MWth / 100 MWe PB-FHR
  - Molten salt coolant
  - Core outlet: 700°C
  - Fuel similar to HTR
  - Increased heat capacity compared to gas cooled HTR
  - Smaller more economic system compared to gas cooled HTR





# WHICH SMR'S?

## LFR: SEALER

- **Swedish Advanced Lead Reactor**
  - Design: LeadCold
  - Lead coolant
  - 8-20 MWth / 3-7 MWe

Potential Demo Site

- Cambridge Bay (Canada)

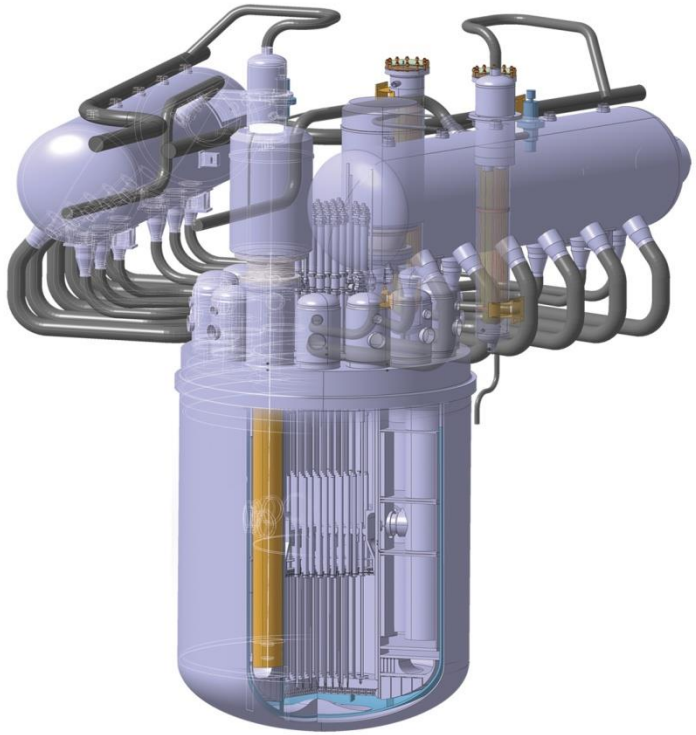
Purpose

- Electricity production for isolated (arctic) communities or mines

# WHICH SMR'S?

## LFR: SVBR

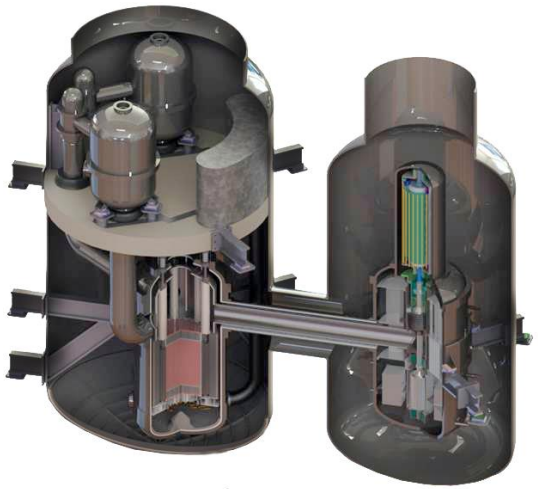
- **Svintsovo-Vismutovyi Bystryi Reaktor**
  - Design: AKME
  - 280 MWth / 100 MWe
  - Core temperature 345 – 495°C
  - Lead-bismuth coolant
  - Integral primary system
  - Forced cooling
  - Refuelling 8 yr
  - License obtained in 2015 for Dimitrovgrad. Need for private investors.
  - Electricity, district heat & desalination

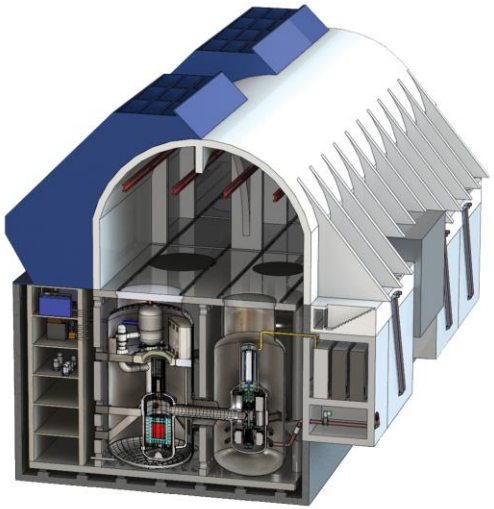


# WHICH SMR'S?

## GFR: EM$^2$

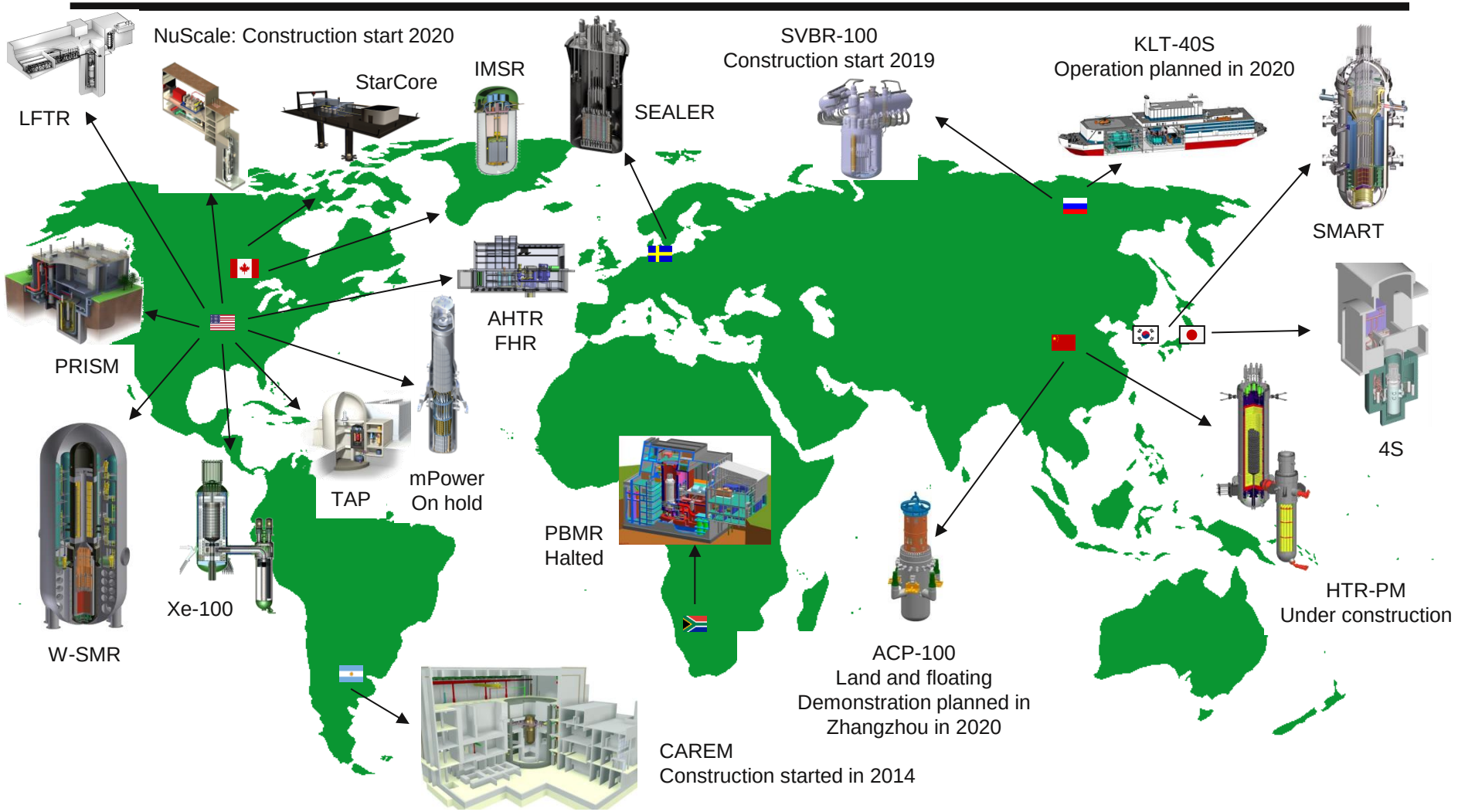
- **Energy Multiplier Module**
  - Design: General Atomics
  - 500 MWth / 240 MWe
  - Core temperature up to 850°C
  - Refuelling 30 yr





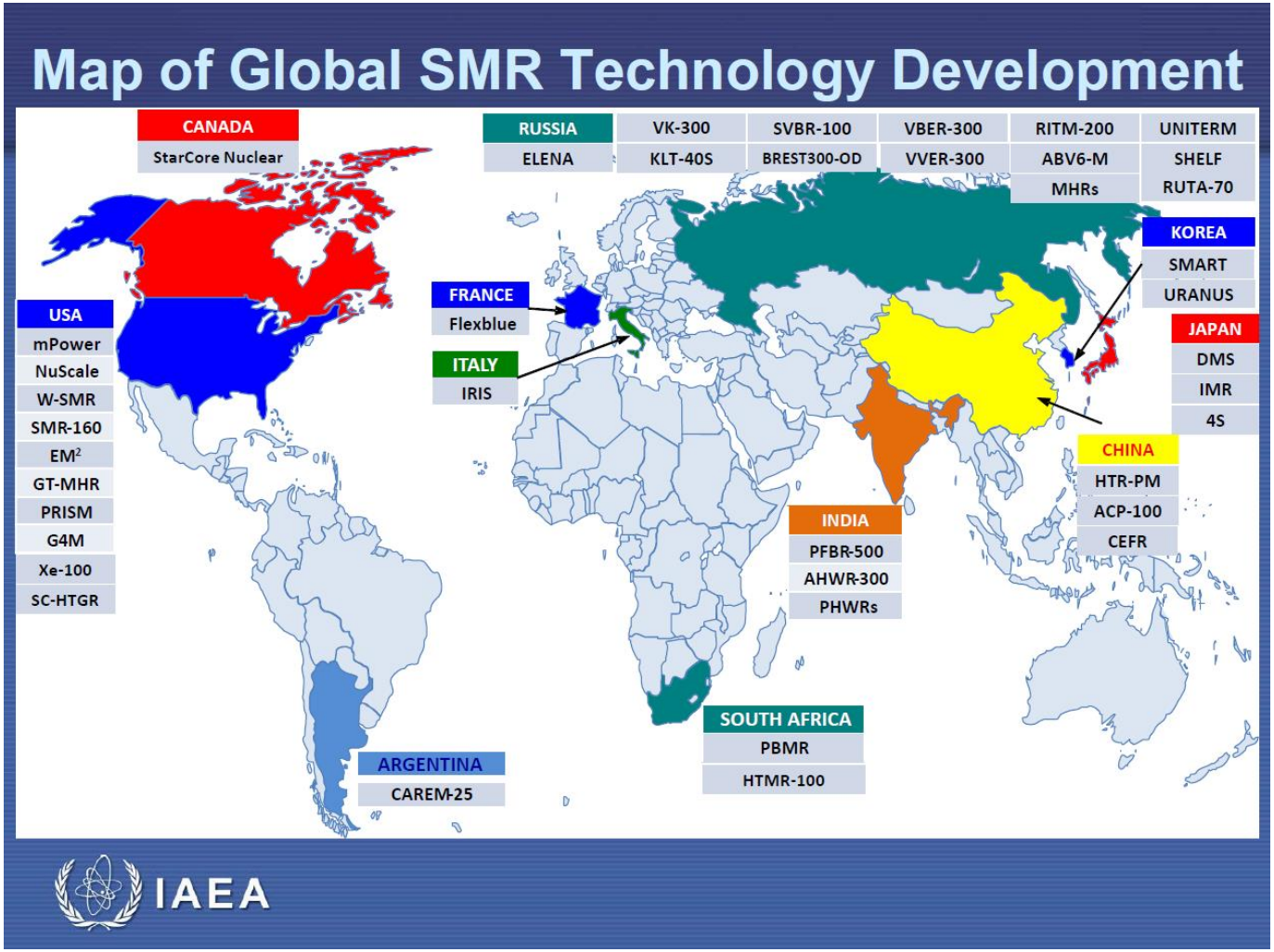
# WHICH SMR'S?

## INTERNATIONAL PLAYING FIELD



# WHICH SMR'S?

## INTERNATIONAL PLAYING FIELD



# DUTCH SMR!

- **GKN**
  **‘Gemeenschappelijke Kerncentrale Nederland’**
  - 1968 - 1997
  - Dodewaard
  - 55 MWe
  - Gen I BWR

# QUESTIONS?