Small and Medium Sized Reactors (SMR)

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Definitions

According to IAEA

- SMR = Small and Medium Sized Reactors
  - Small-sized reactors → smaller than 300 MWe
  - Medium-sized reactors → from 300 to 700 MWe
  - Regardless of being modular or non-modular
  - Covers all reactors in-operation and under-development with power < 700 Mwe
  - Covers 1970s technology to 2000s innovative technology

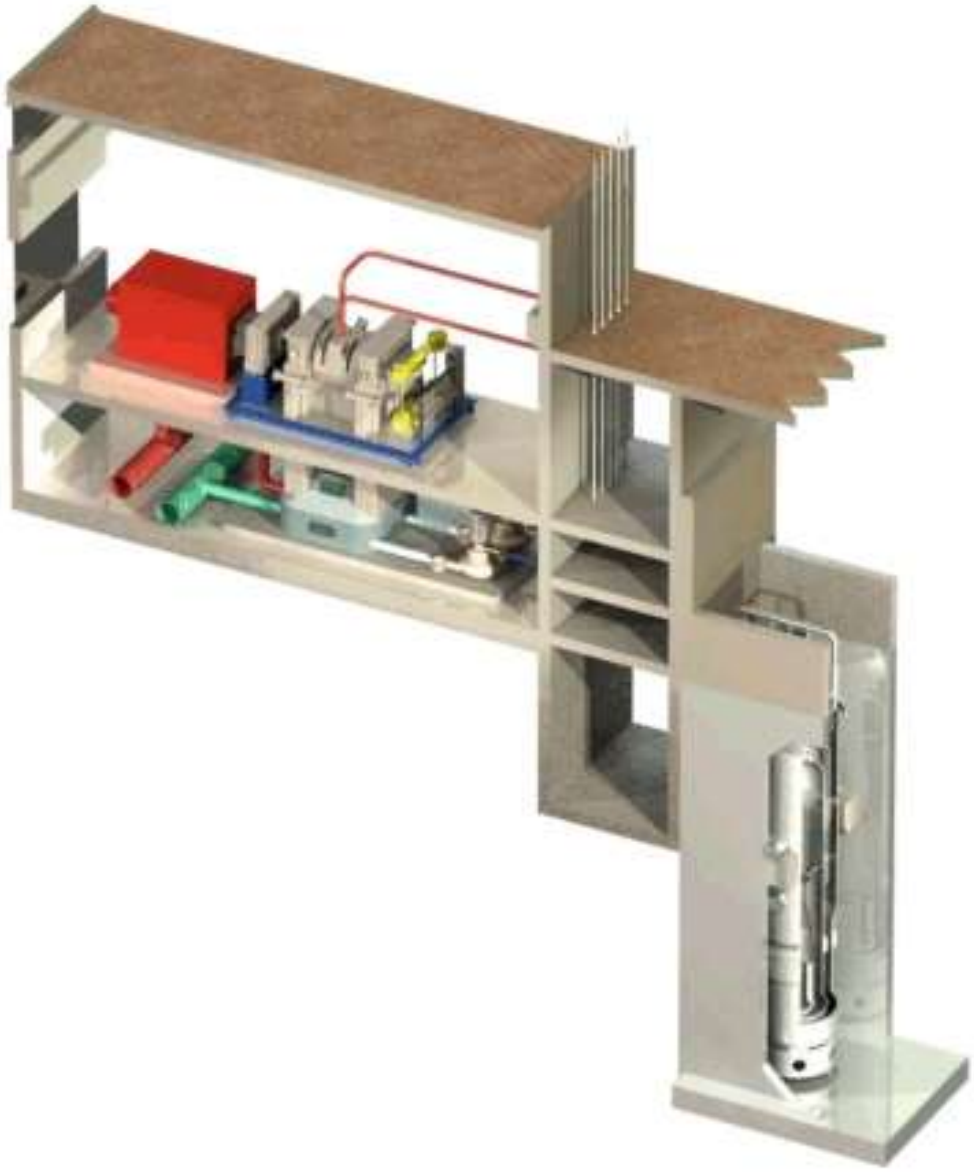
According to recent trends

- SMR = Small Modular Reactors
  - Small-sized reactors → smaller than 300 Mwe
  - Emphasize the benefits of being small and modular
  - Focus on innovative reactor designs under-development

Modular?

- The reactor is factory-built in smaller modules and it is assembled on site like a Lego.

- A nuclear unit is composed of various reactor modules. Individual reactor modules can be added at separate times depending on power demand needs.



Single-unit side view of the NuScale system design

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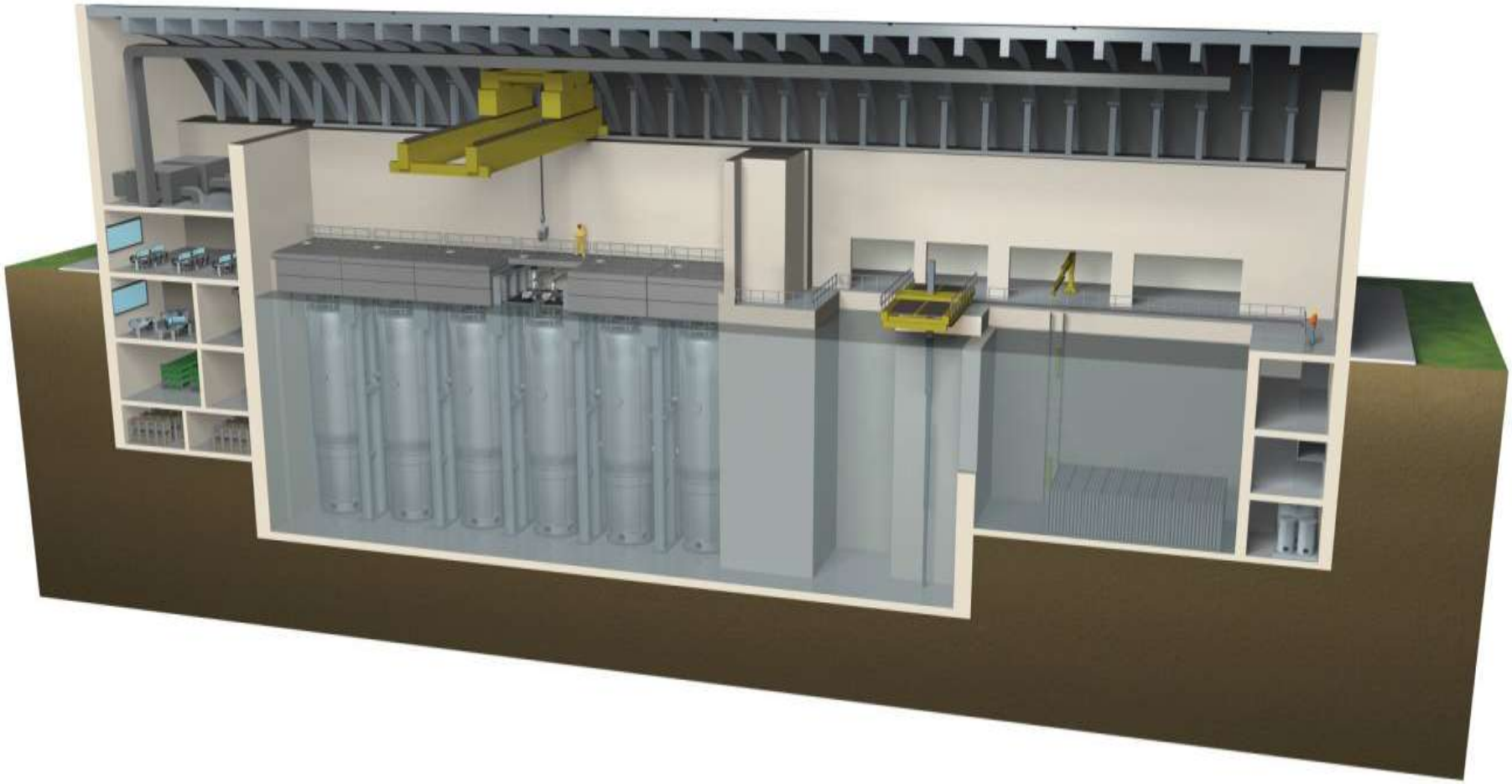


NuScale Plant
12 modules, 45 MWe each
produces a total 540 MWe

Global Development and Deployment

- Many SMRs (with 1970s and 1980s technologies) have long been in operation and many are under construction
- Dozens of concepts for innovative SMRs are under development: Argentina, Brazil, Canada, China, France, India, Japan, Republic of Korea, Russia, South Africa, USA, and some emerging countries.
- A number of companies are developing SMRs - each has unique features and varying megawatt capacity.
- None of the innovative SMRs are commercially available

Types

- Light Water Cooled SMRs
  - Deployment = 10 years
  - CAREM, mPower, W-SMR, NuScale, Smart, ACP-100, KLT-40
- Non-LWR fast reactor SMRs
  - Deployment = 15 -20 years
  - Liquid metal or gas cooled (4S, PRISM, PBMR)
- Advanced designs
  - Deployment = 20+ years
  - Molten salt, others?

Operational Benefits

- Safety
  - Passive safety systems
  - Integral designs
- Flexibility
  - Adaptable to grid size
  - Suitable for remote areas
  - Electricity or process heat
- Simplicity
  - Less components, cabling, piping
  - Factory fabrication
  - Reduced construction times
- Security
  - Below grade emplacement

Economic Benefits

- Expected to be competitive with large LWR costs/KWe ($4-5K/KWe)
  - Economies of series vs economies of scale
- Lower initial construction costs
  - Affordability vs low capital cost
- Electrical capacity can be added in smaller increments to match demand growth

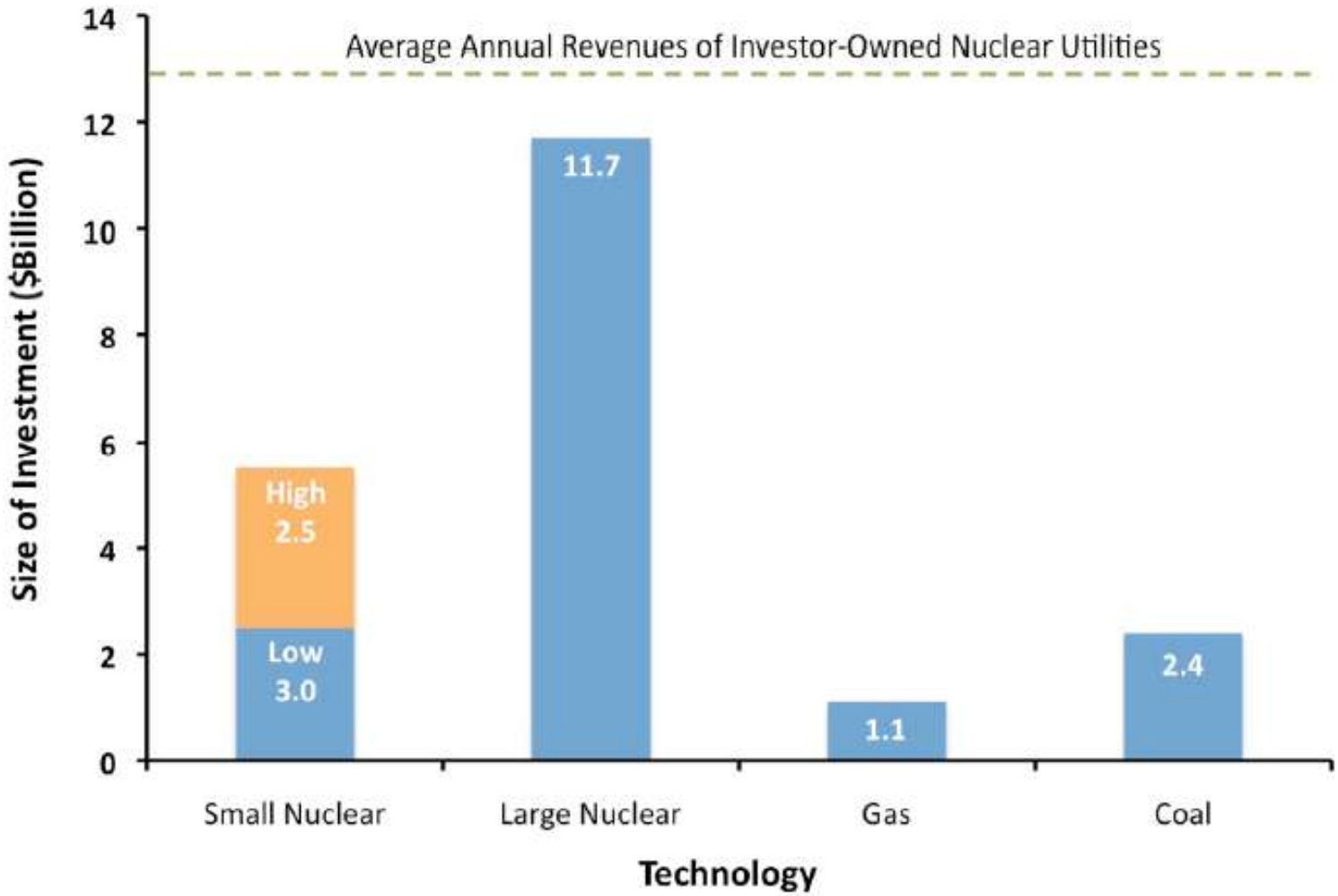


FIGURE 1 Comparison of Size of Investment (i.e., Overnight Cost) with Average Annual Revenues of Investor-Owned Nuclear Utilities[17]

Source: "Small Modular Reactors – Key to Future Nuclear Power Generation in the U.S.", University of Chicago, Nov 2011

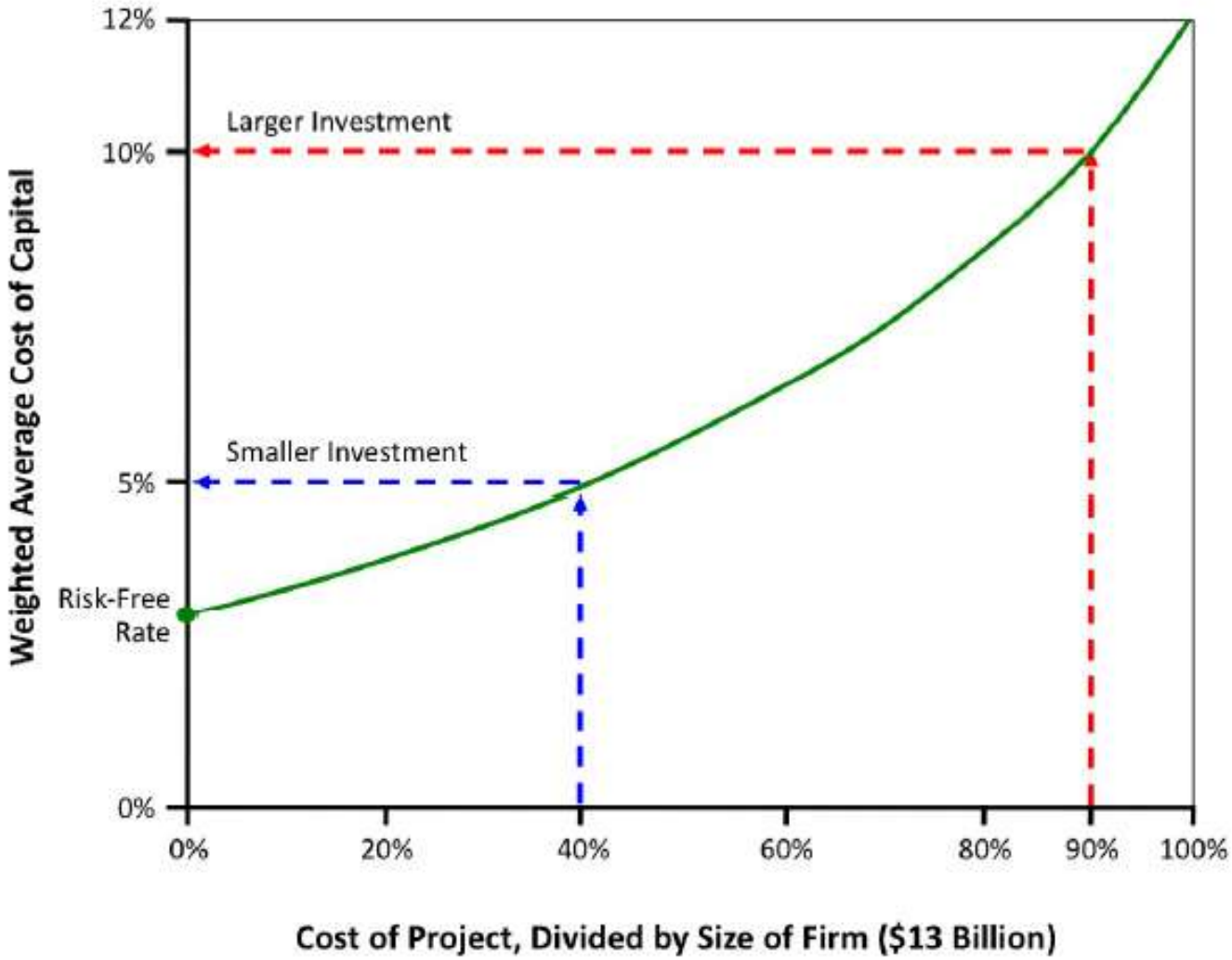


FIGURE F.1 Firm's Investment in Nuclear Reactor Project for SMRs and GW-LWRs[82]

Source: "Small Modular Reactors – Key to Future Nuclear Power Generation in the U.S.", University of Chicago, Nov 2011

Technology Advantages

- Shorter construction period
  - Modularization
  - Factory fabrication
- Potential for enhanced reliability and/or safety (??)
- Reduced complexity in design and human factors
- Suitability for non-electrical applications (i.e. process heat and desalination)
- Grid appropriate
  - Tolerance to grid instabilities
  - Suitable to distributed grids
  - Capable of load following (??)

Technology Challenges

- Licensability
  - delays due to design innovation
- Non-LWR technologies
- Operability
- Spent fuel management and waste handling policies
- Impact of innovative design and fuel cycle to proliferation resistance

Non-Technical Advantages

- Suitable for smaller electricity grids
- Options to match demand growth by incremental capacity increase
- Site Flexibility
- Lower upfront investment capital cost per installed unit
- Easier financing scheme

Non-Technical Challenges

- Economic competitiveness
  - economies of scale vs economies of series
  - First-of-a-kind cost estimate vs Nth-of-a-kind
- Proposed reduced emergency planning zone
- Regulation for fuel or NPP leasing
- Limited market opportunities
- Availability of design for newcomers
- Infrastructure requirements
  - Supply chain
  - Manufacturing capabilities

Big Picture Concerns

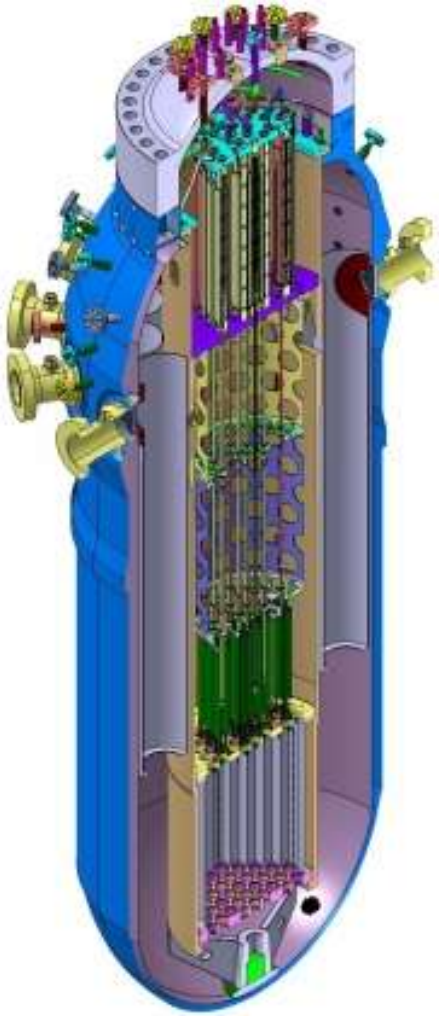
- First of a kind engineering
- Innovative fuel/core design and fuel cycle
- Viability of multiple-modules station (post-Fukushima)
- Proliferation resistance and physical security
- Ergonomics and control room staffing
- Emergency planning zone
- Mechanistic source term
- Standardization and licenses for manufacturing
- Technology transfer and proprietary design protection
- Codes and Standards
- Users and Owners issues

Conclusions

- SMR maybe an attractive nuclear power option
  - for countries with small electricity grids and/or less-developed electrical infrastructure
  - More affordable
- Potential for near-term deployment but much work yet to be done
- Innovative SMR concepts have similar technology development challenges: licensability, competitiveness, financing schemes
- Economics: $/kWe to be built? $/kWe-hr to operate?
- Needs to implement lessons-learned from Fukushima events into the design, safety, economic, financial, licensing, and public acceptance for SMRs

CAREM (Central Argentina de Elementos Modulares)

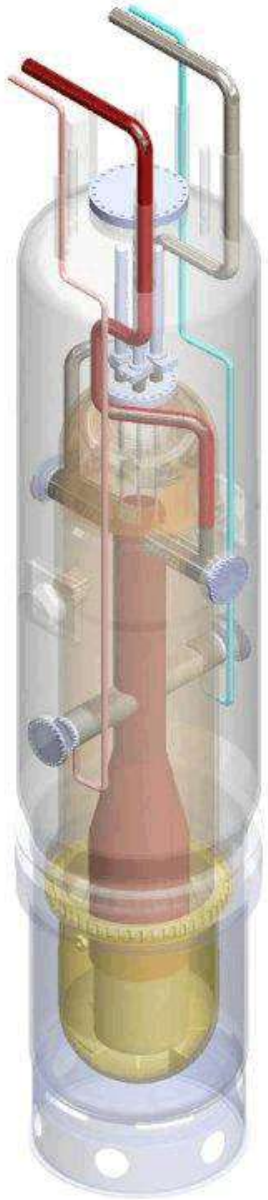
- Developed by INVAP and Argentine CNEA
- Prototype: 25 MWe
- Expandable to 300 MWe
- LWR
- Integral reactor
- Passive safety
- Used for electric and non-electric applications
- Nuclear Safety Assessment under development
- Prototype planned for 2012 in Argentina's Formosa province



B&W mPower

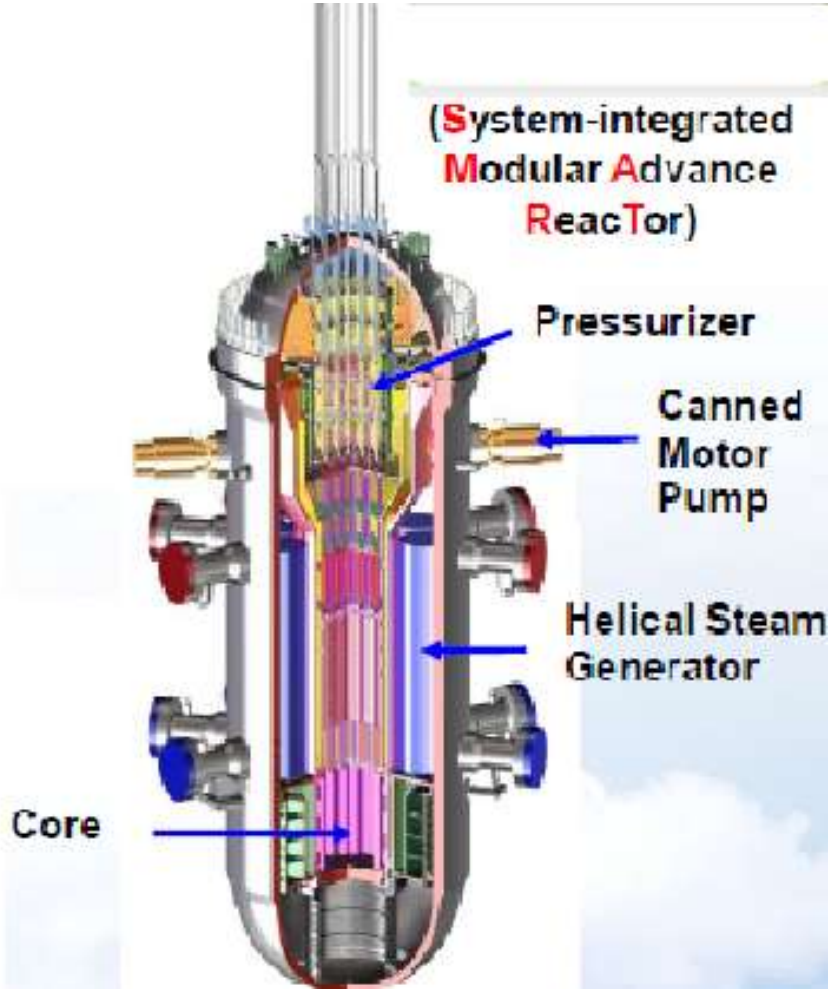
- LWR
- Integral reactor
- Scalable, modular
- 125 – 750 MWe
- 5% enriched fuel
- 4 year refueling cycle
- Passive safety
- Air-cooled condenser
- Lifetime capacity of spent fuel pool

NuScale



- Oregon State University (USA)
- 45 MWe
- LWR
- Integral reactor
- Modular, scalable
- Passive safety
- Online refueling (??)
- Working on Design Certification with US NRC.

SMART



- Korea Atomic Energy Research Institute
- 330 MWe
- Used for electric and non-electric applications
- LWR
- Integral reactor
- Passive Safety

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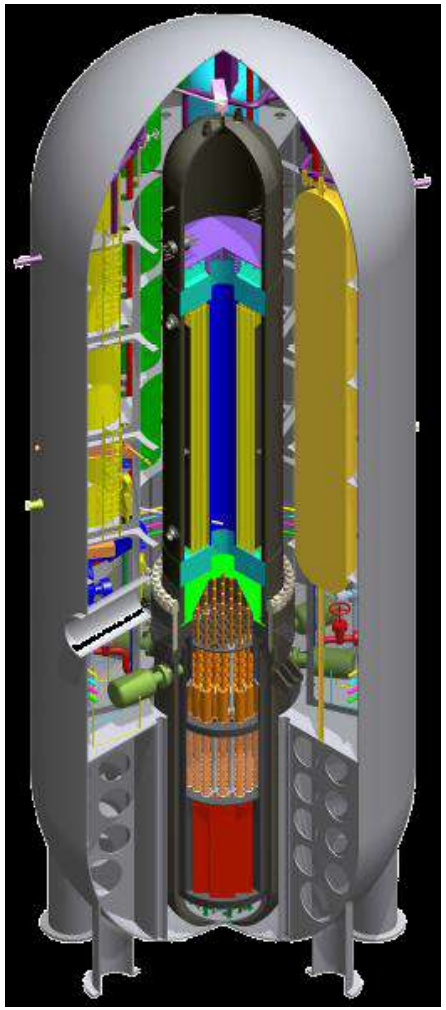
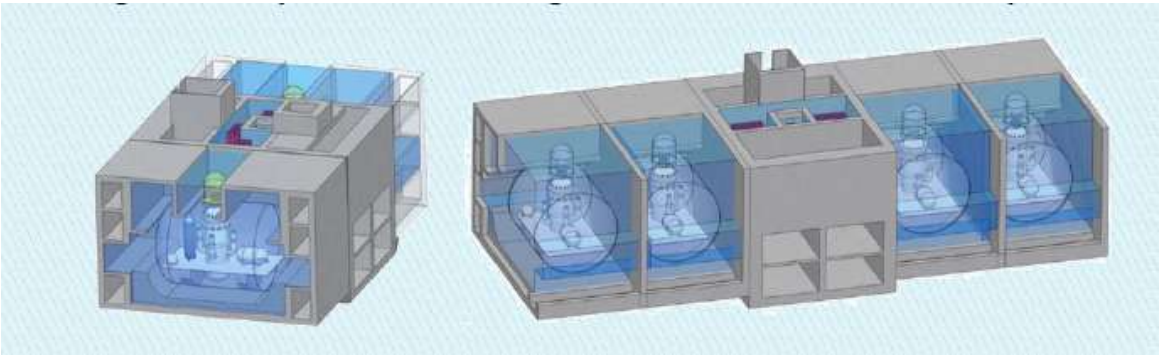
Westinghouse SMR

- An integral PWR
- 225 MWe
- Innovative packaging of proven components
- Industry-proven equipment designs
- Compact reactor coolant system and containment
- One reactor per unit

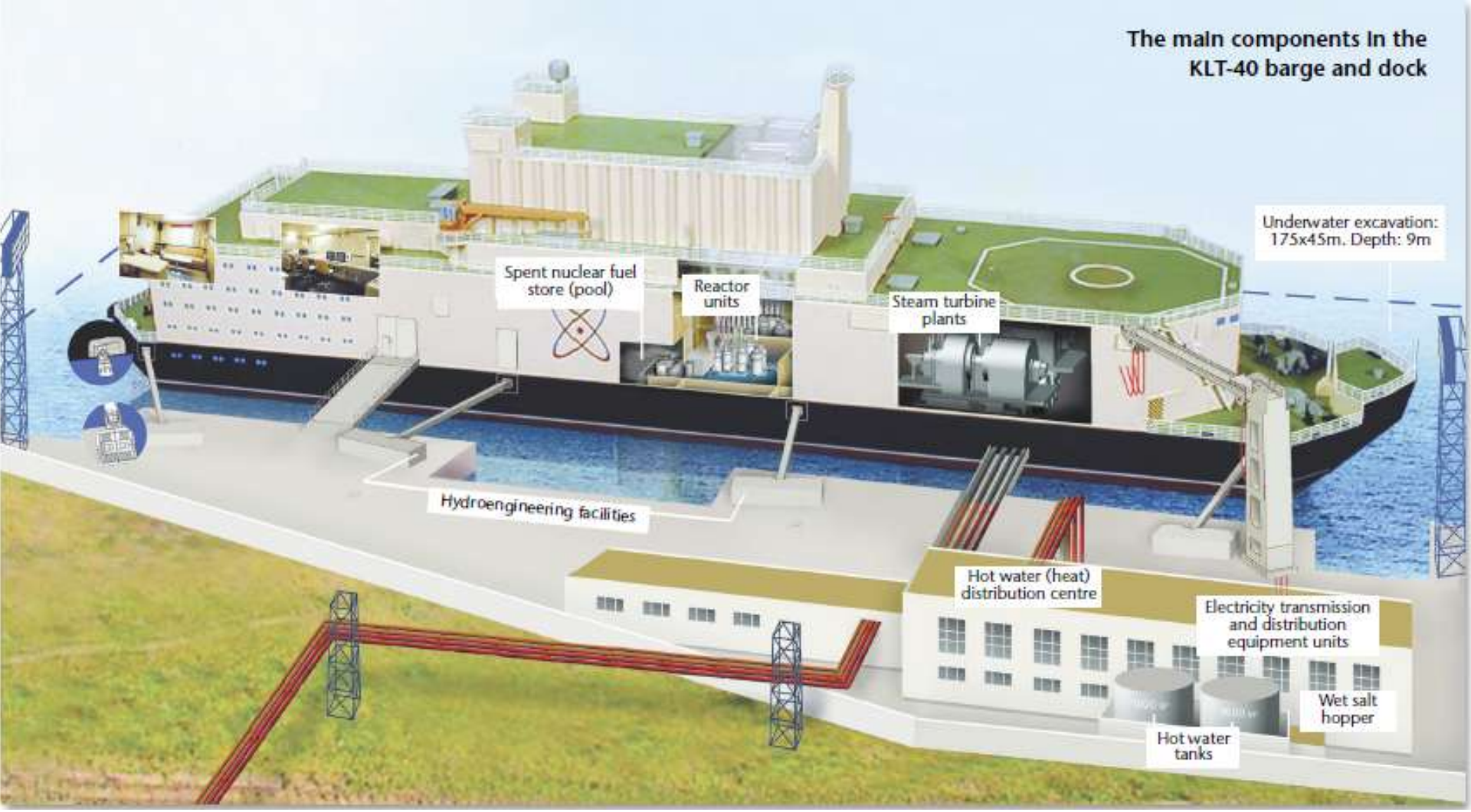


ACP-100

- CNNC in China
- 100 MWe
- LWR Integral
- Up to 8 modules per unit
- Prototype planned for Putian City

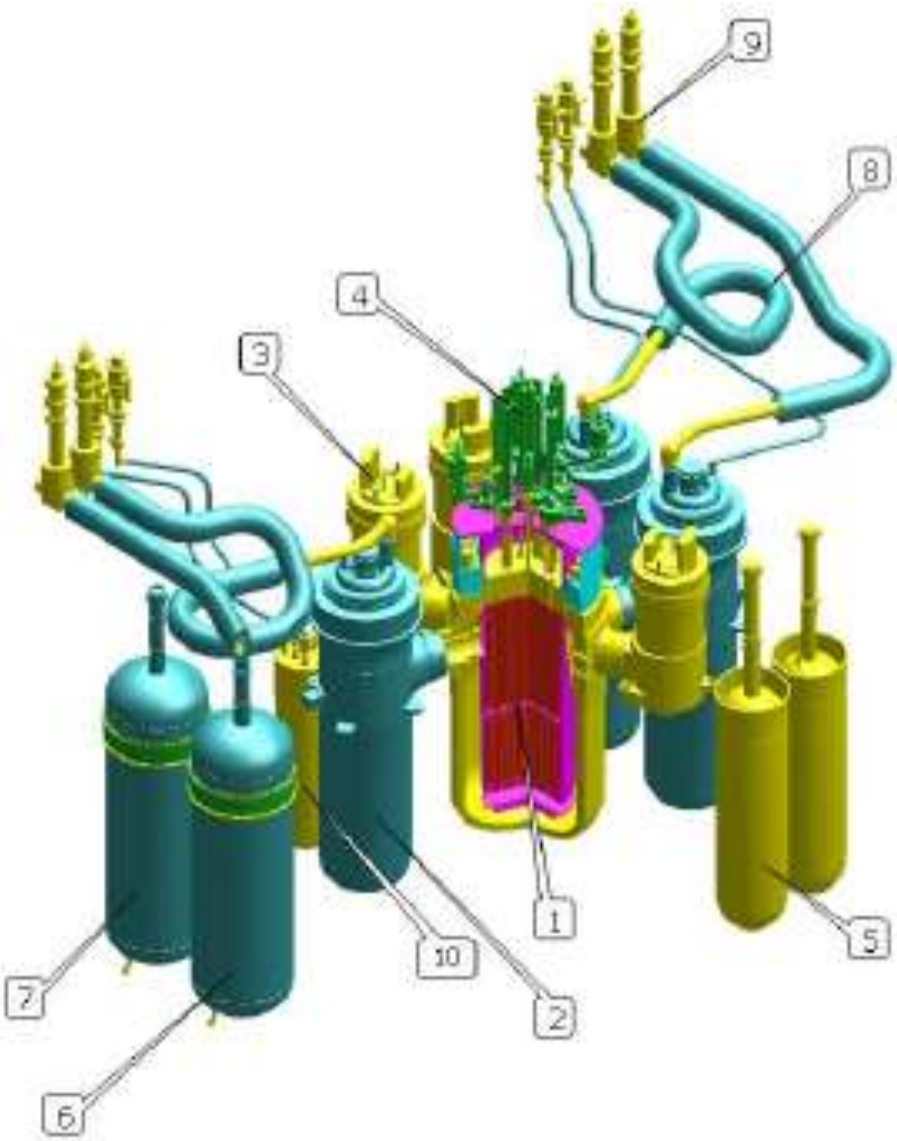


KLT-40


The main components in the KLT-40 barge and dock
Underwater excavation: 175x45m. Depth: 9m
Spent nuclear fuel store (pool)
Reactor units
Steam turbine plants
Hydroengineering facilities
Hot water (heat) distribution centre
Electricity transmission and distribution equipment units
Wet salt hopper
Hot water tanks

KLT-40

- NOT LAND BASED: on a ship
- Reactor output: 300 MWt, 60 MWe net
  - Efficiency: 23.3 %
  - Target Availability: 85 %
  - Plant life: 40 yr
- 4 loop PWR with load follow capability
- Electric and non-electric applications




РИАНОВОСТИ

Power Reactor Innovative Small Module (PRISM)

- GE-Hitachi
- Liquid metal (Na)
- Metal fuel
- 311 MWe
- Part of a strategy to close the nuclear fuel cycle

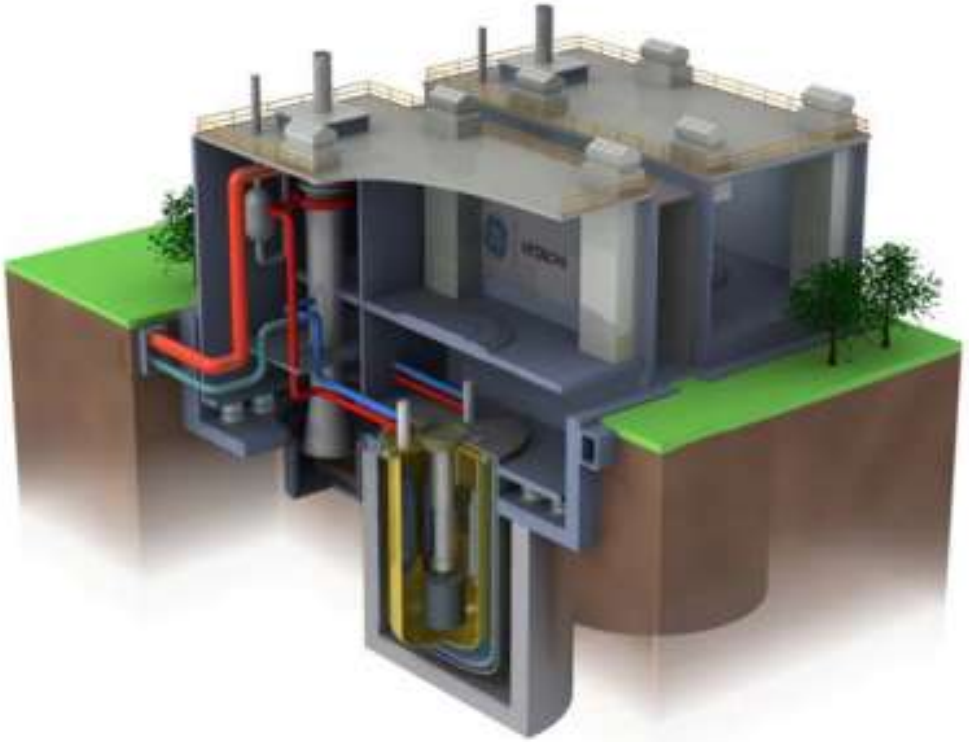
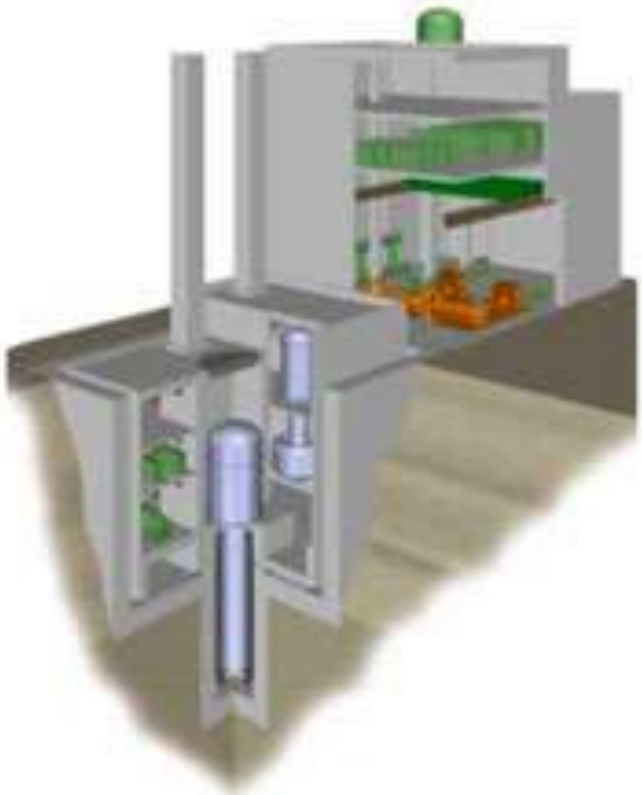


Figure 2: PRISM Reactor power block used to produce electricity from spent nuclear fuel.

4S (Super Safe, Small and Simple)

- Toshiba & CRIEPI of Japan
- 50 MWe
- Sodium Cooled Fast Reactor
- 10 – 30 year refueling period
- Submitted for US NRC Pre Application Review
- Proposed for Galena, Alaska



TerraPower Travelling Wave Reactor

- A reactor that breeds its own fuel
- The fission reaction takes place in a small area of the reactor and moves to where the fissionable fuel is being created.
- Breed-and-burn

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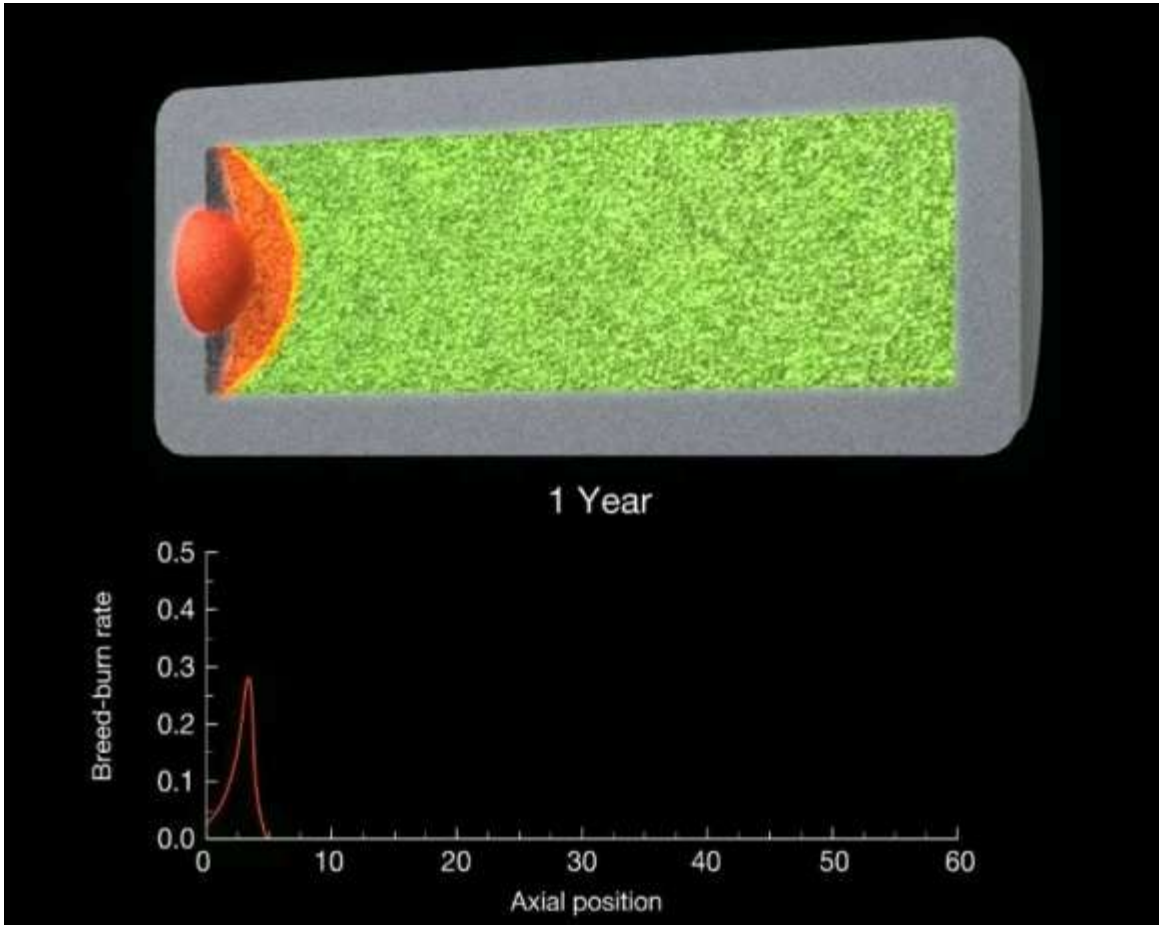
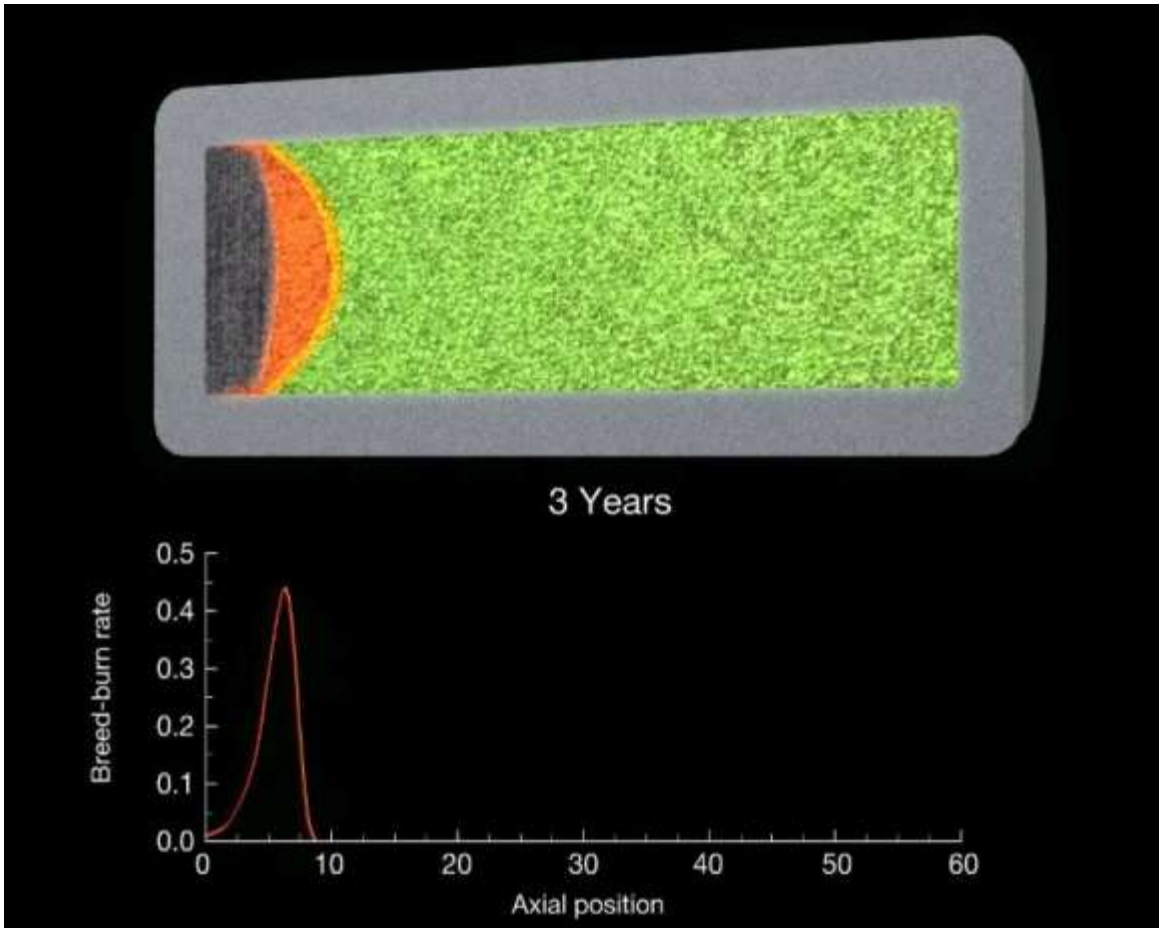
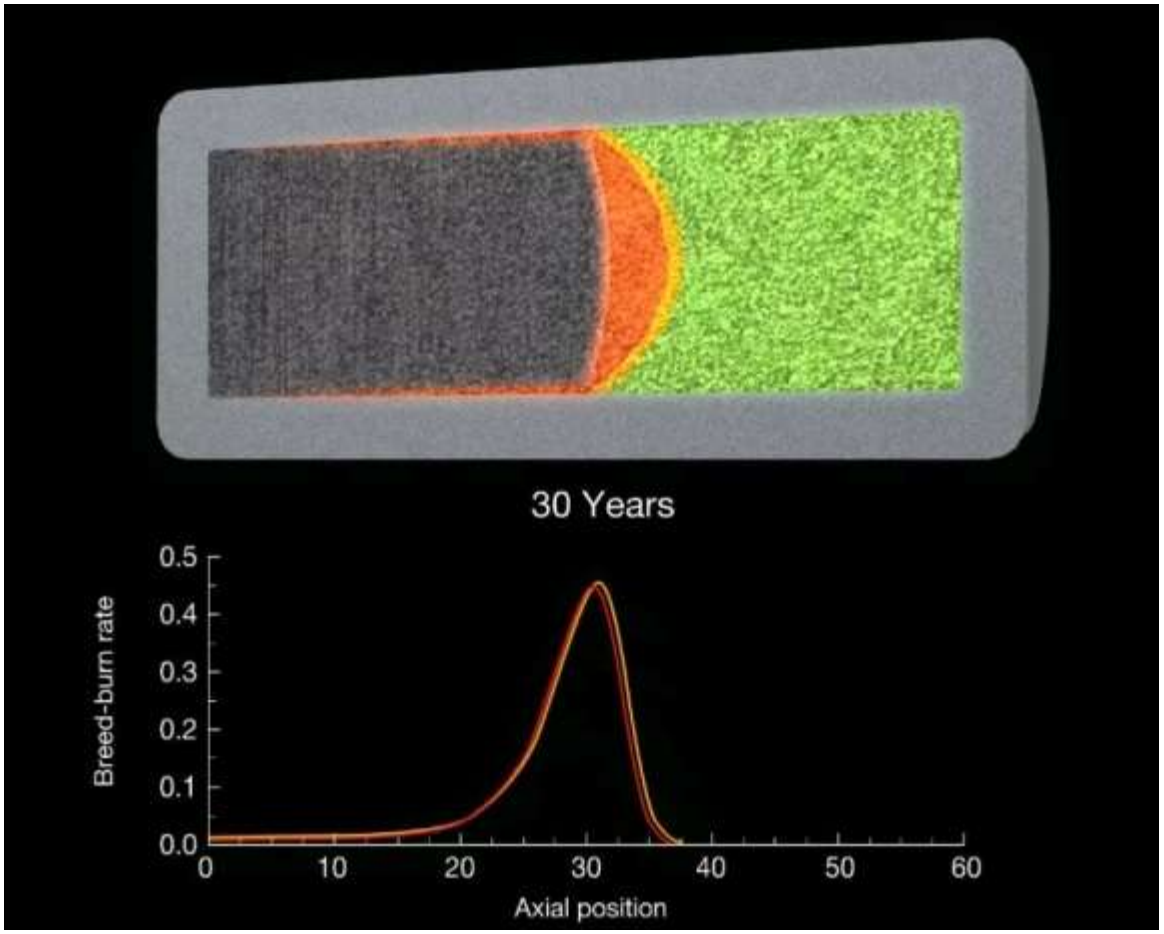
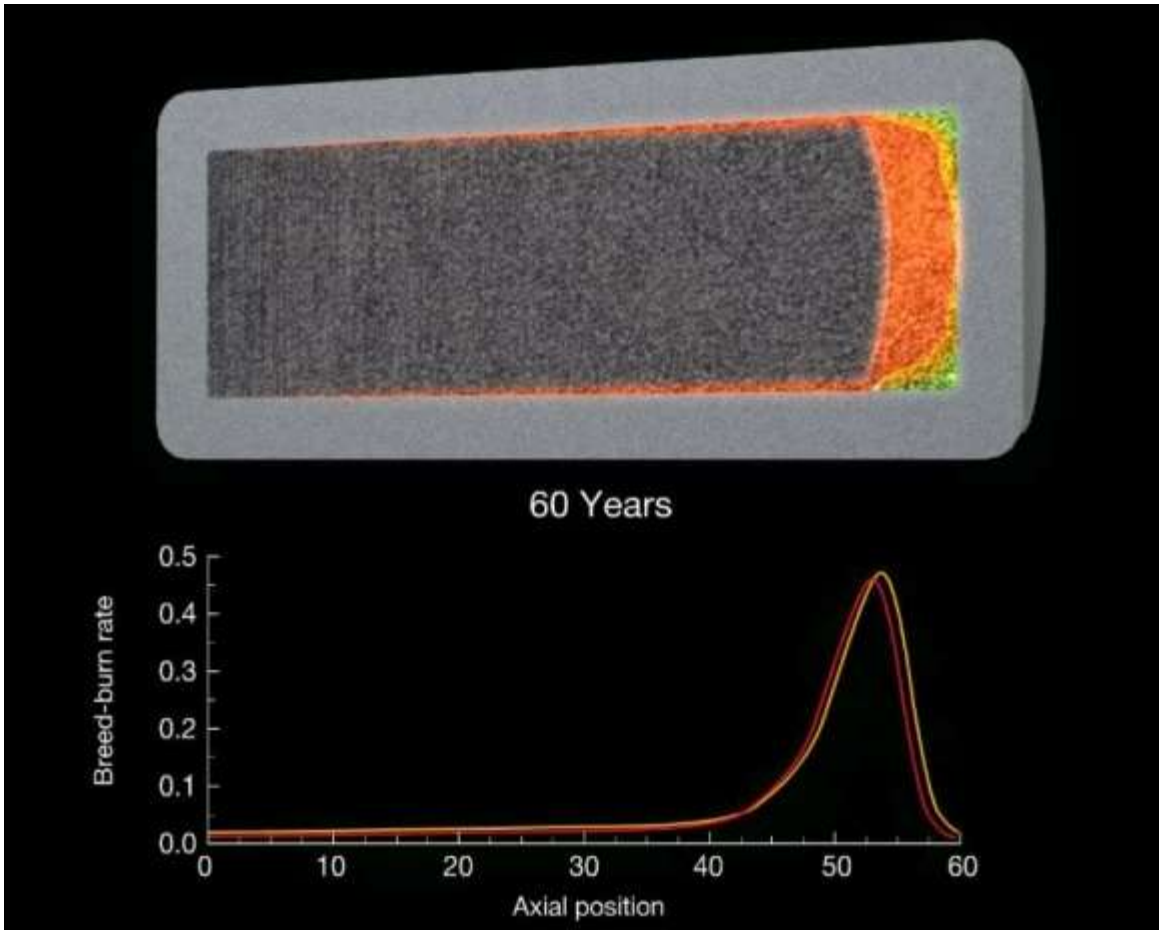

1 Year
Breed-burn rate
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
Axial position

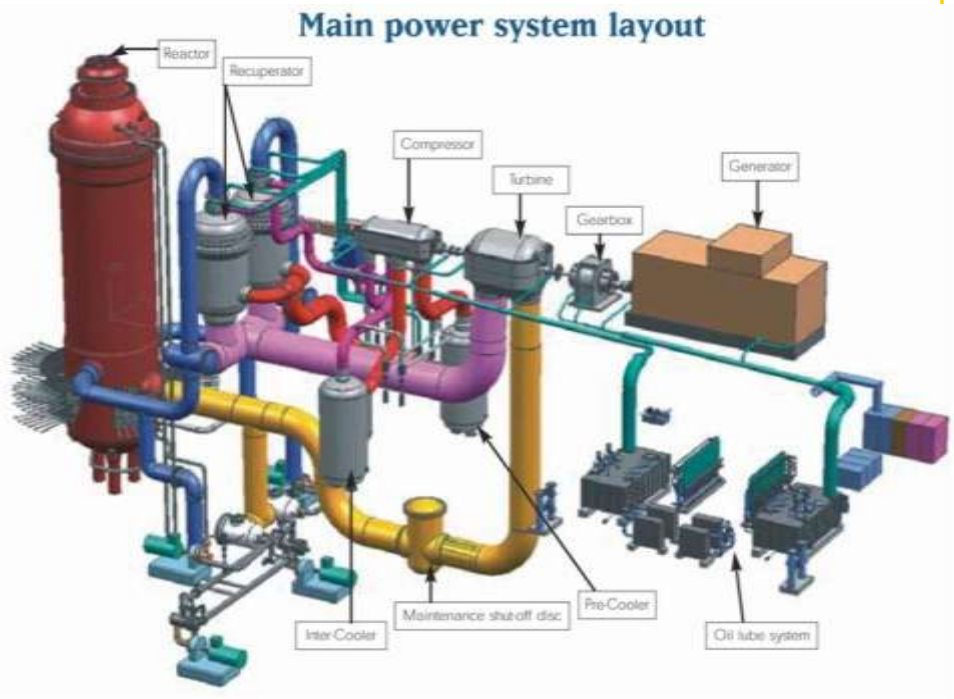

3 Years
Breed-burn rate
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
Axial position


30 Years
Breed-burn rate
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
Axial position


60 Years
Breed-burn rate
0.5
0.4
0.3
0.2
0.1
0.0
0
10
20
30
40
50
60
Axial position

PBMR (Pebble Bed Modular Reactor)

- ESKOM, South Africa Government, Westinghouse
- Helium Gas Cooled
- 165 MWe
- Electrical and non-electrical applications
- Project mothballed in 2010



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