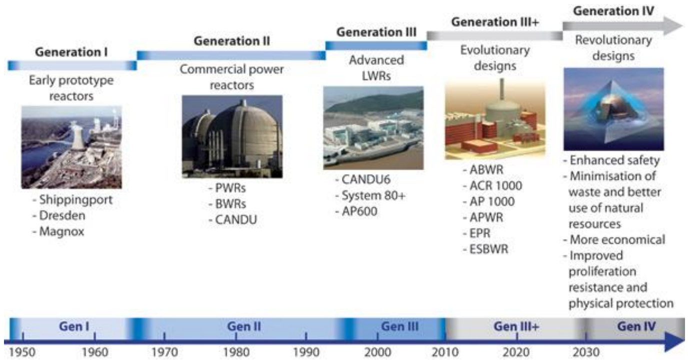
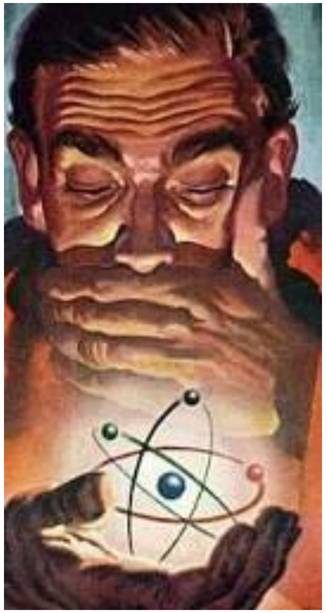


Gerações III+ e IV

SMR

Fusão

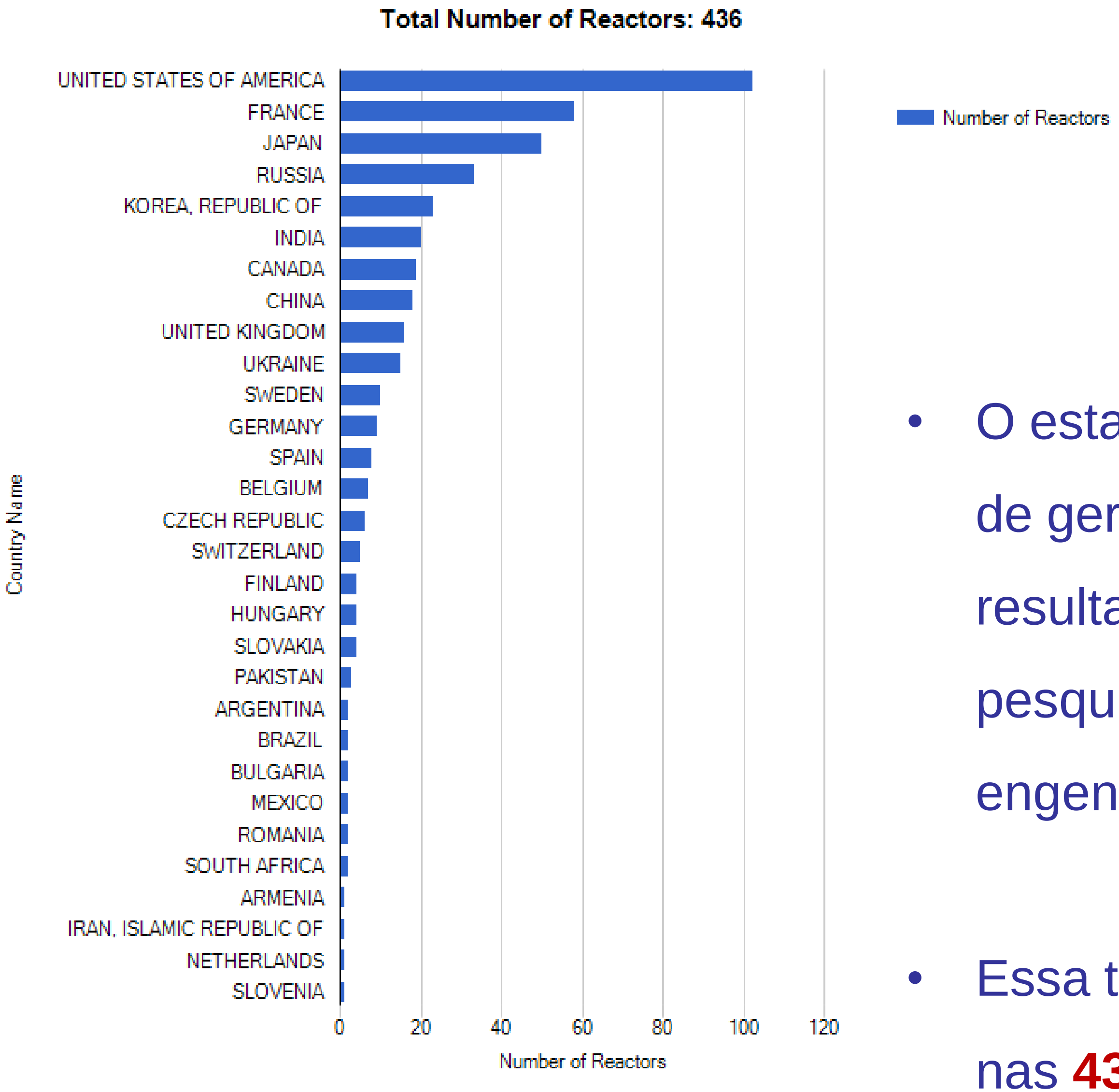


Futuro Tecnológico da Geração Nuclear

INAC 2013, Recife, 27 de novembro de 2013

New Technologies for Nuclear Power

Leonam Guimarães, Diretor Técnico-Comercial da AMAZUL SA

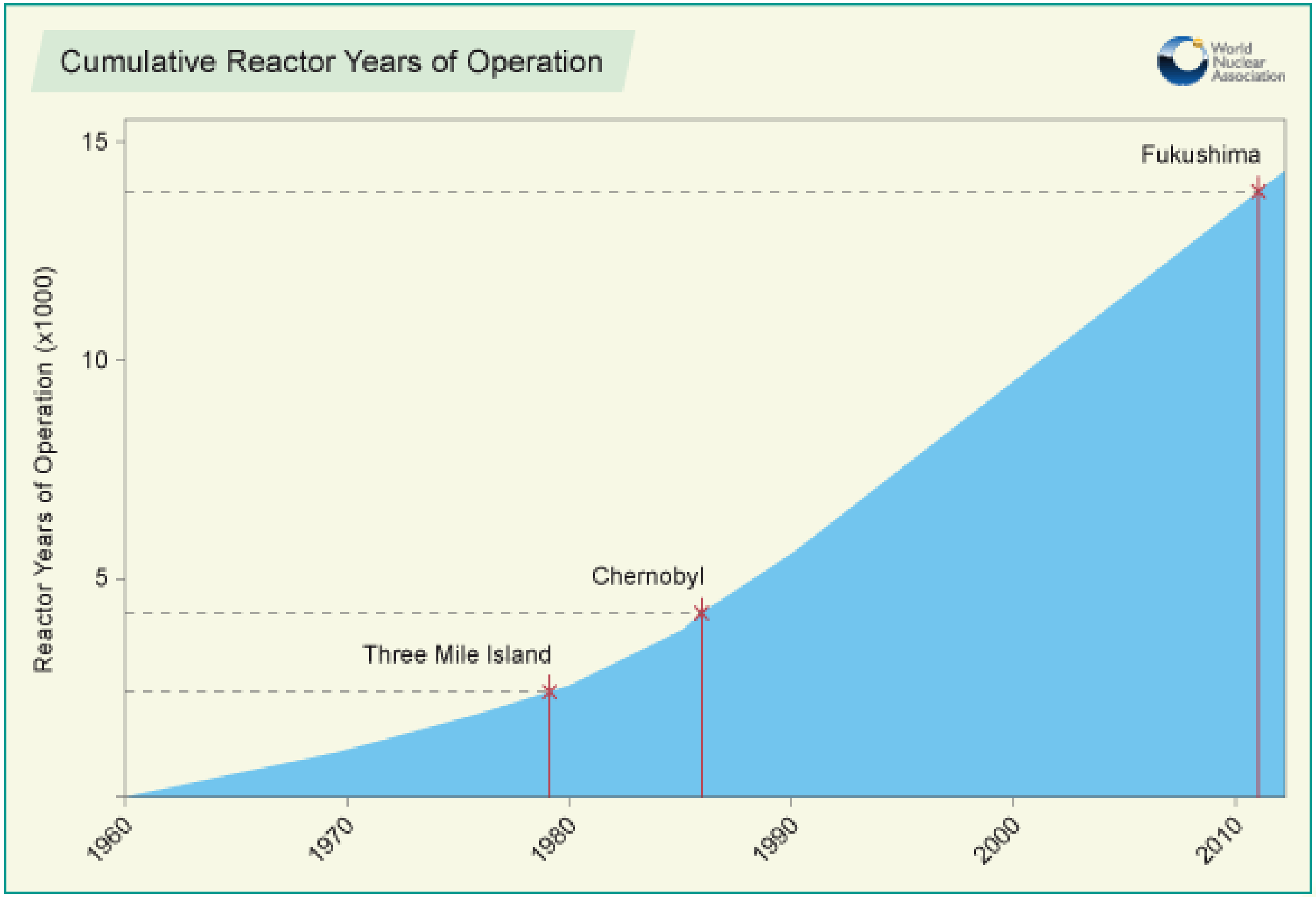


Parque de Geração Nuclear Mundial em Operação

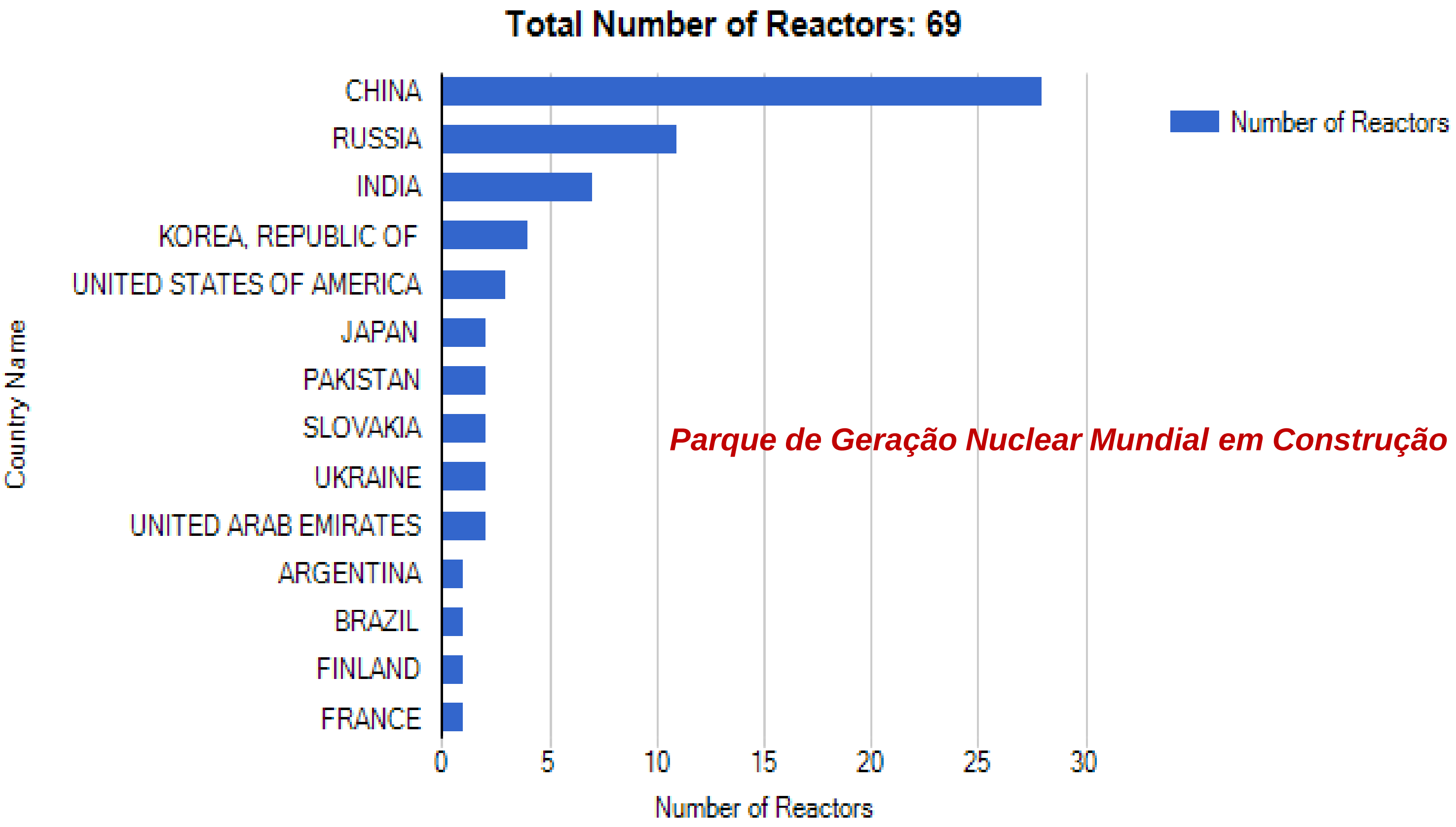
- O estado-da-arte da tecnologia de geração elétrica nuclear é o resultado de mais de 50 anos de pesquisa, desenvolvimento e engenharia.

- Essa tecnologia está consolidada nas **436 usinas nucleares** atualmente **em operação**.

- Esse parque, ao qual se soma as usinas já descomissionadas, representa uma **experiência operacional cerca de 15.000 reatores-ano**



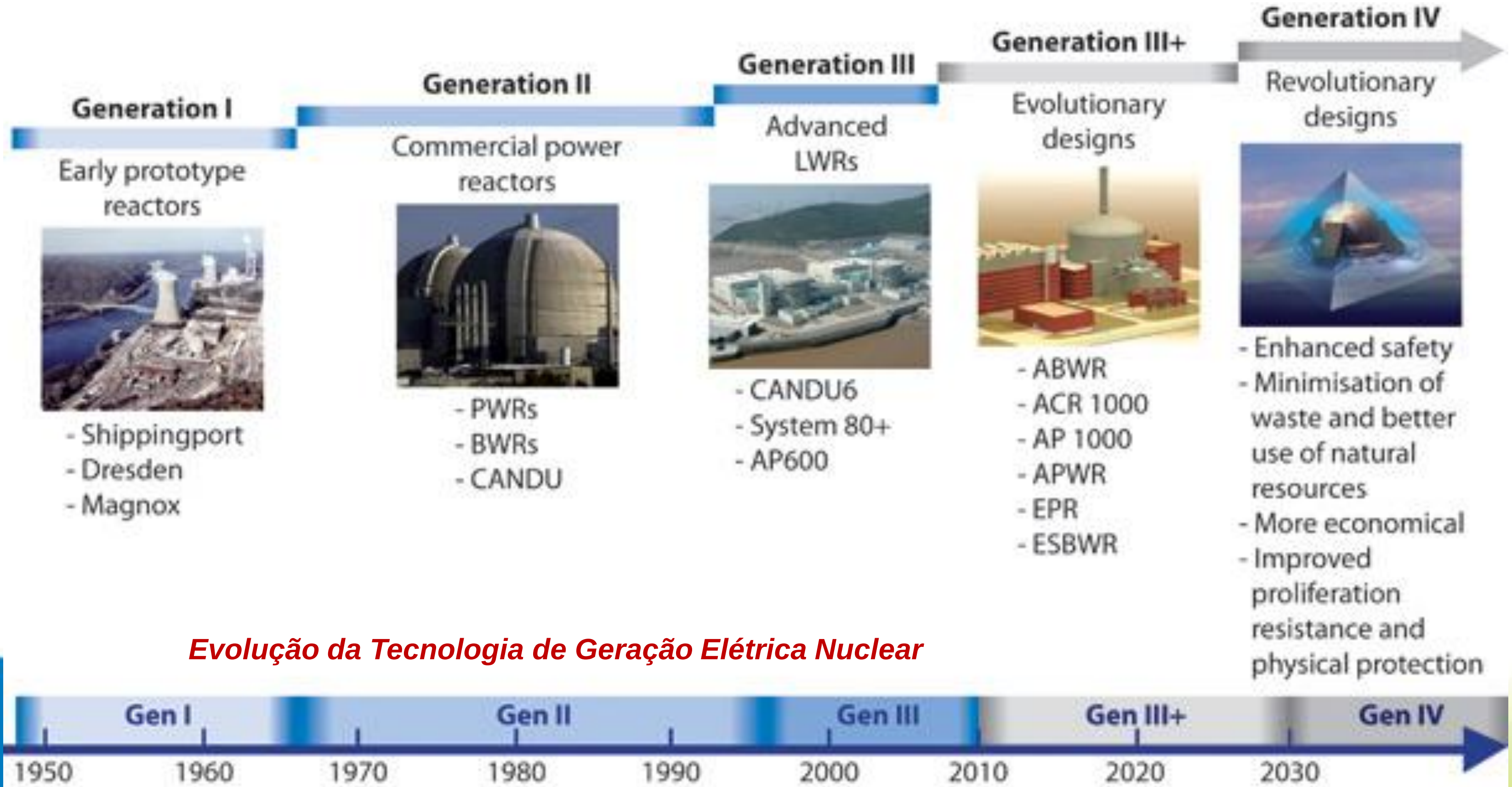
Experiência operacional acumulada (em reatores-ano)



Parque de Geração Nuclear Mundial em Construção

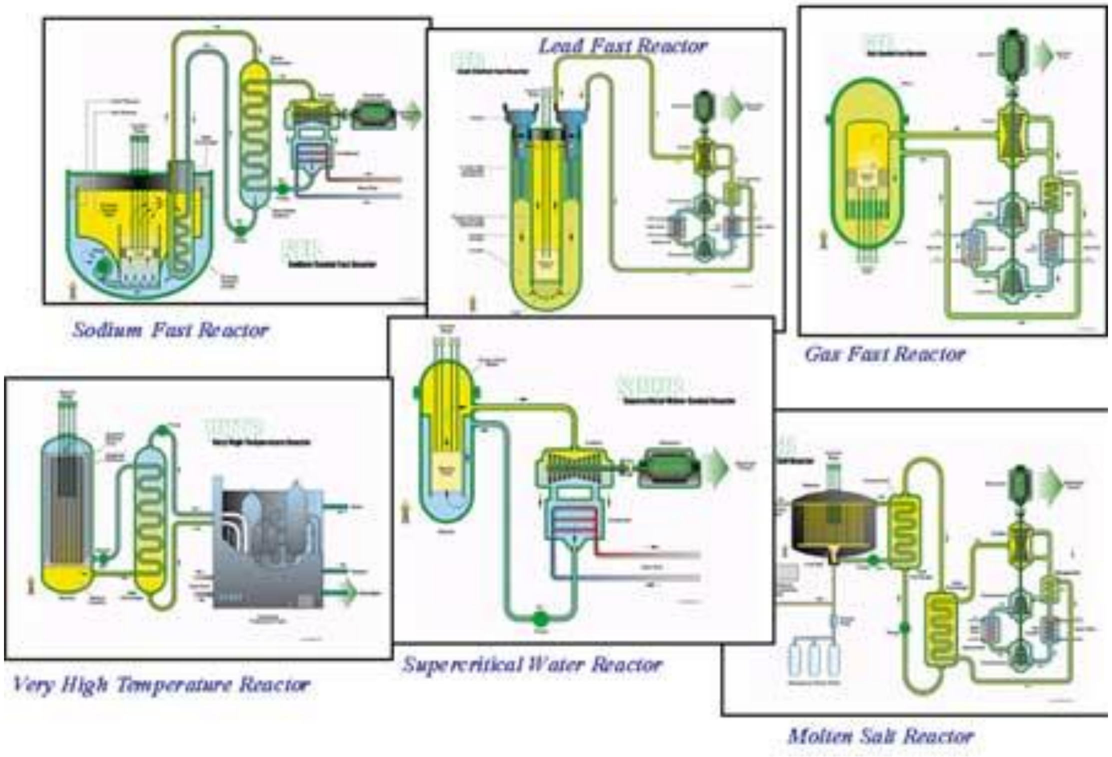
- Os modernos projetos de usinas nucleares, hoje em construção, incorporam lições aprendidas dessa experiência assim como os mais recentes **avanços tecnológicos para melhoria da segurança e da produtividade.**
- **A geração nuclear é uma tecnologia madura**
  - com muito baixa emissão de carbono, que se encontra disponível hoje para ampla utilização

- as primeiras usinas comerciais são de **“Geração I**”.
- as usinas que compõem o parque em operação são de “**Geração II**”.
- Os projetos incluindo evoluções tecnológicas são chamados de “**Geração III**”.
  - continuam reatores resfriados a água com combustível óxido de urânio mas com:
    - I&C digital, dispositivos para acidentes severos (recuperador de “corium”).
    - “**Geração III+**”**,** quando incluem dispositivos inovadores de segurança intrínseca, como resfriamento passivo por circulação natural



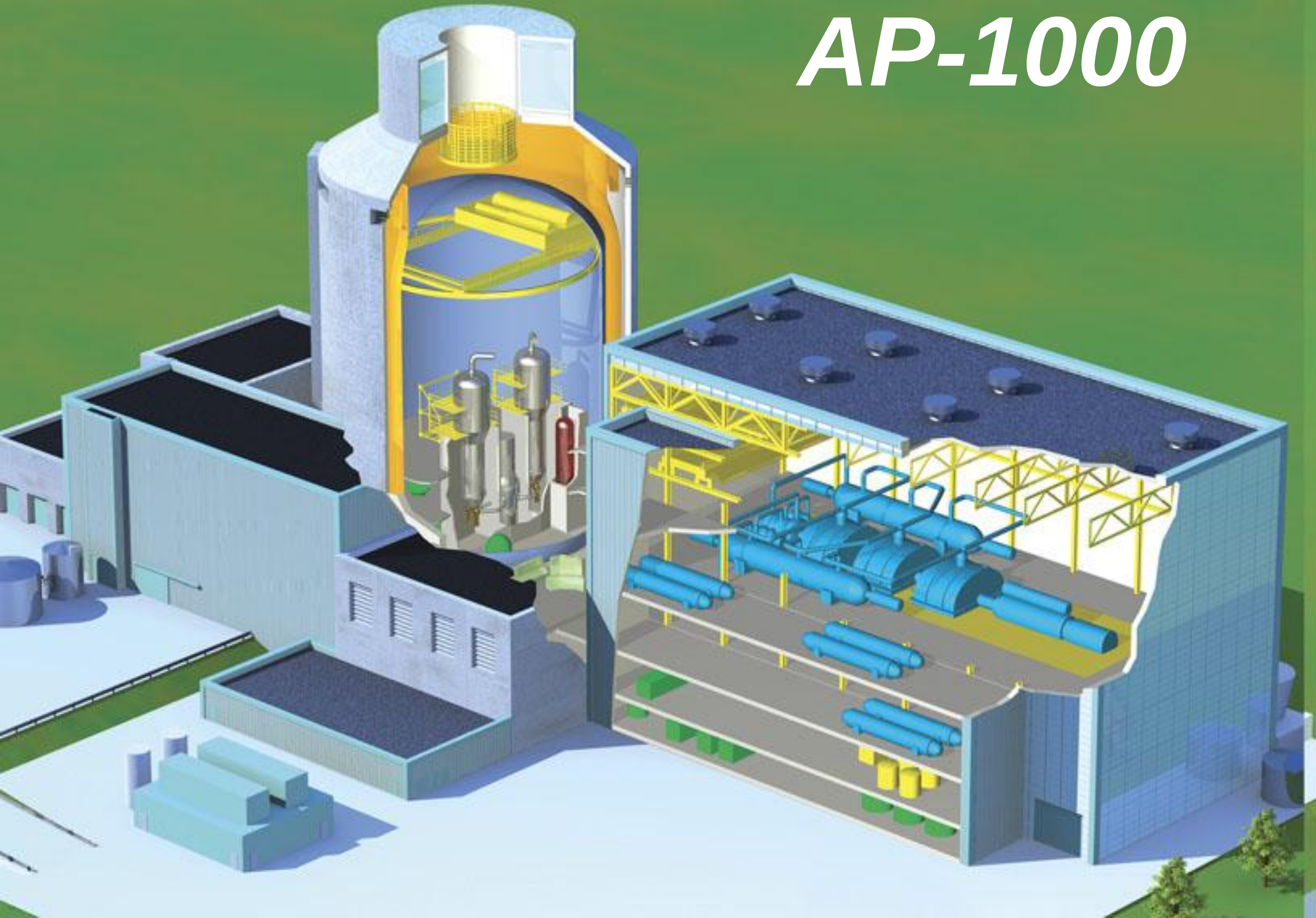
Evolução da Tecnologia de Geração Elétrica Nuclear

Geração IV: seis sistemas inovadores



- Encontram-se também em pesquisa e desenvolvimento reatores nucleares para emprego **após a década de 2020**, chamadas de “**Geração IV**”.
- São conceitos bastante diversos dos atuais, empregando **novos tipos de combustíveis e fluidos de resfriamento**.

AP-1000



AP-1000

resfriamento passivo

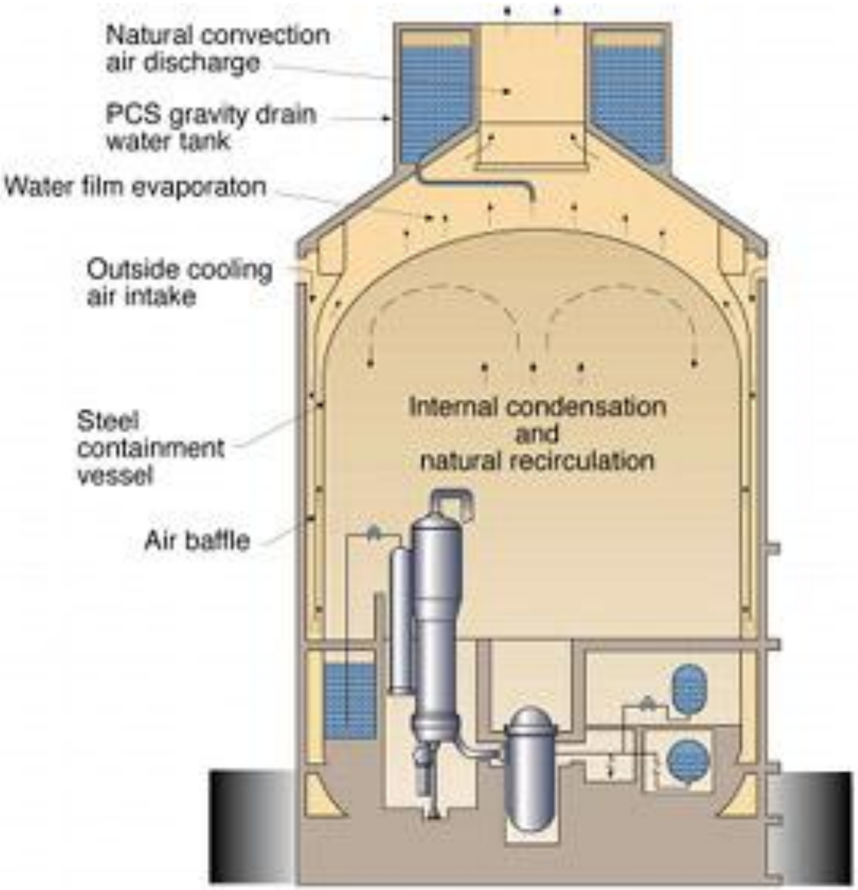
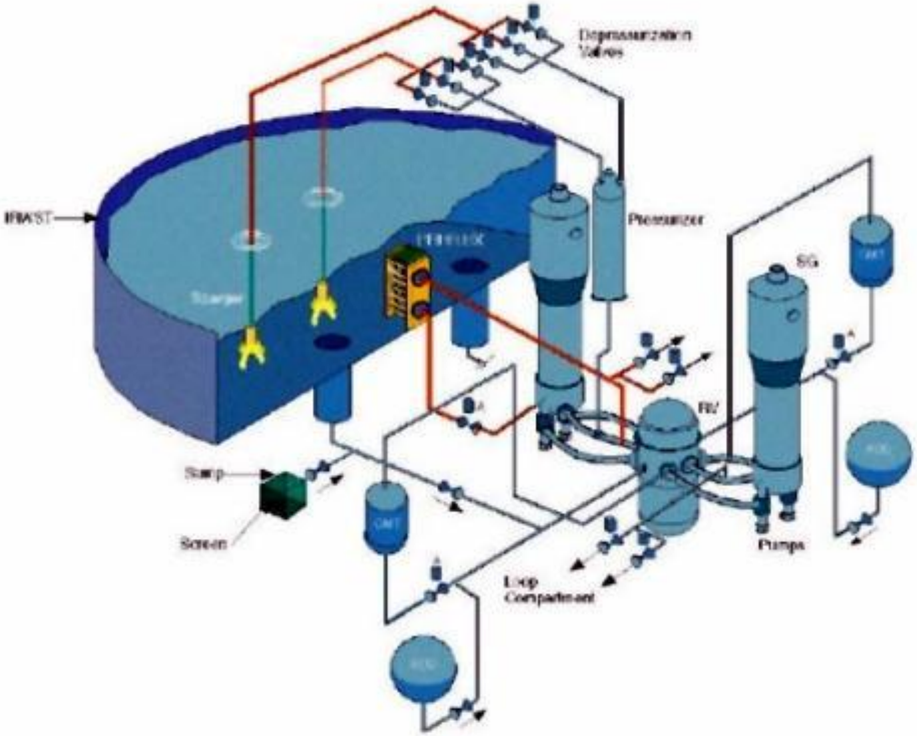


Figure 3. AP600 Passive Containment Cooling System

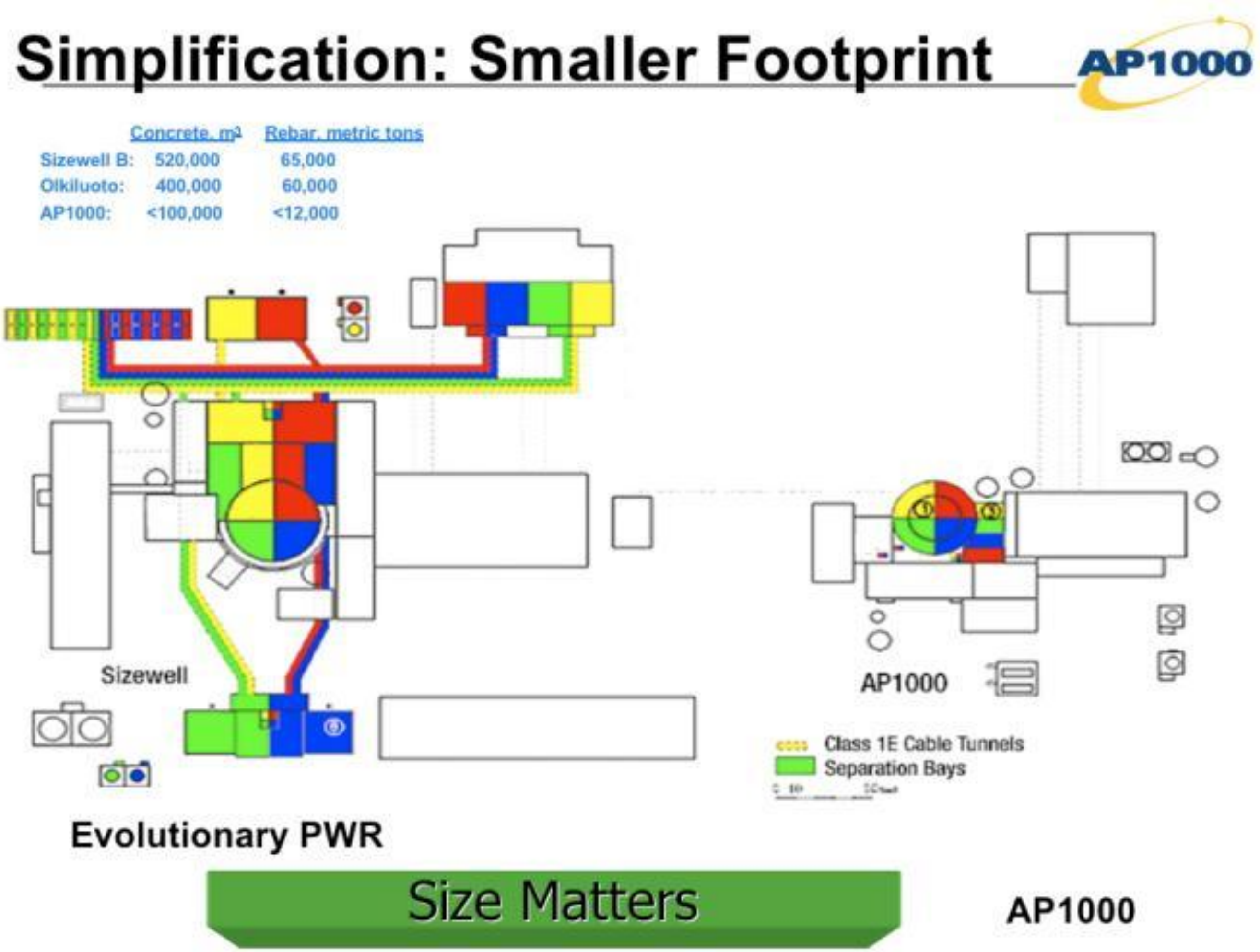


AP1000 Passive core cooling system

Source: ansaldonucleare.it

AP-1000

simplificação

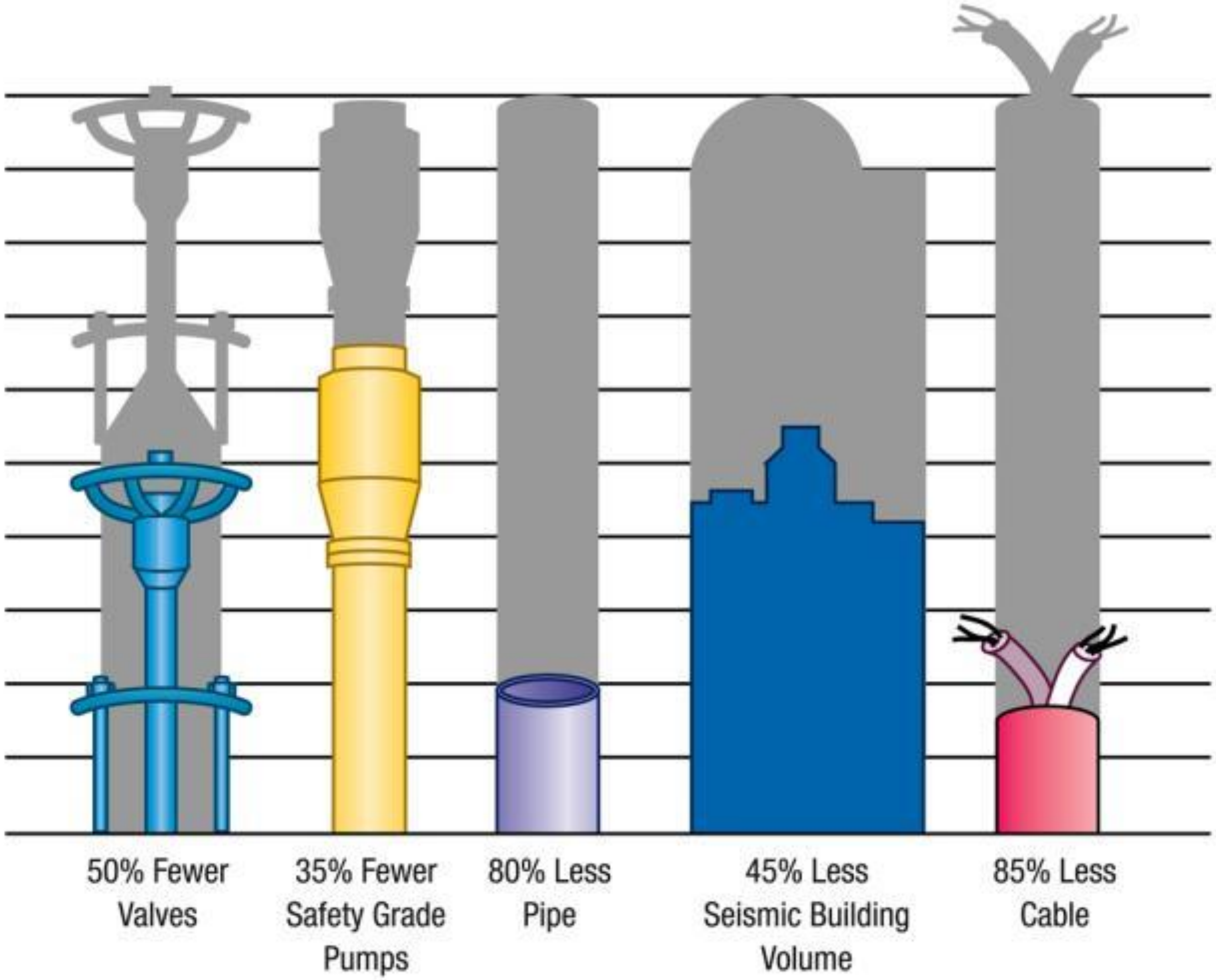


Simplification: Smaller Footprint

	Concrete, m³	Rebar, metric tons
Sizewell B:	520,000	65,000
Olkiluoto:	400,000	60,000
AP1000:	<100,000	<12,000

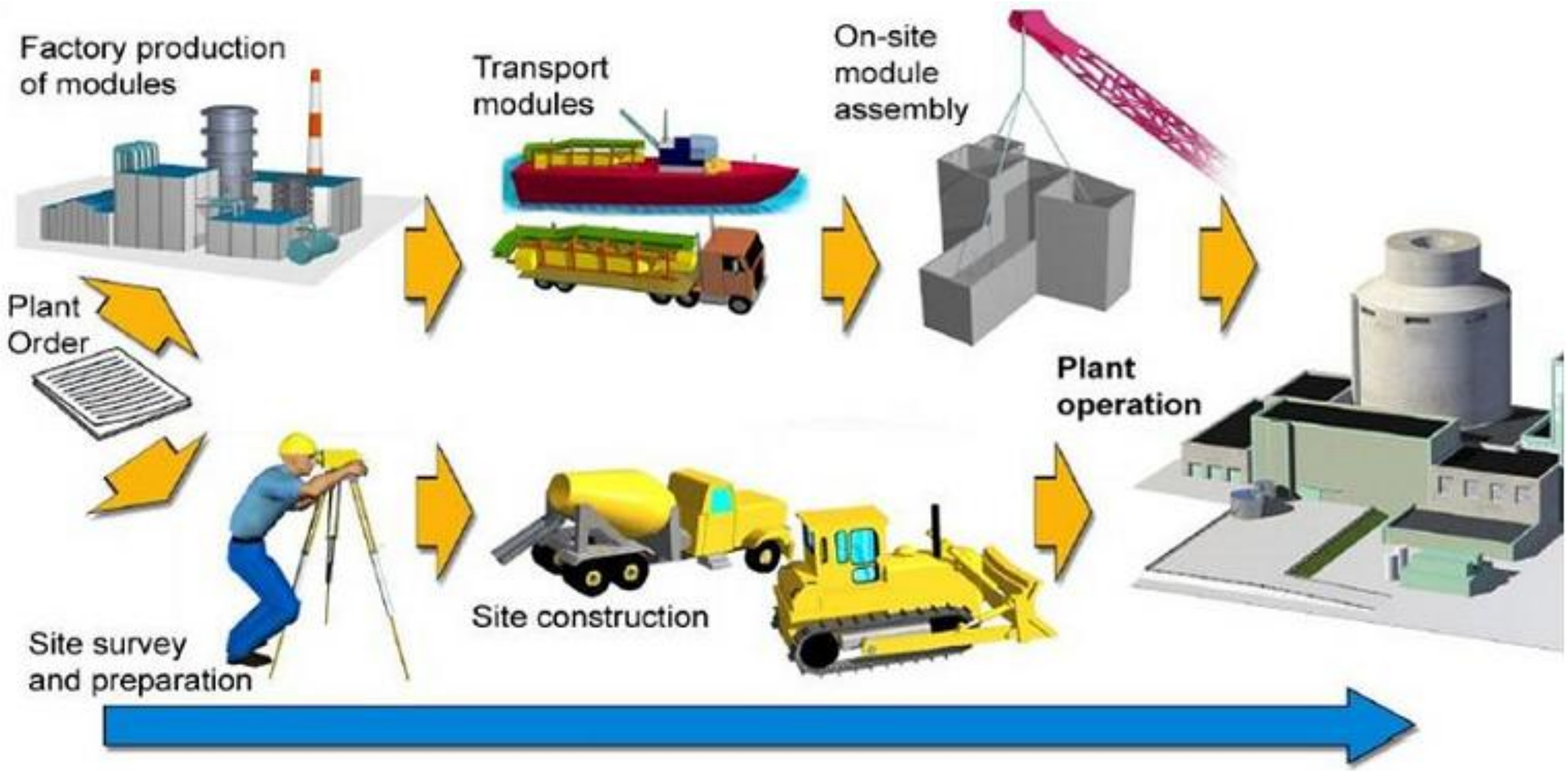
AP-1000

simplificação



AP-1000

construção modular



AP-1000

Sanmen (China)

Construction of the Sanmen AP1000 first continues according to plan

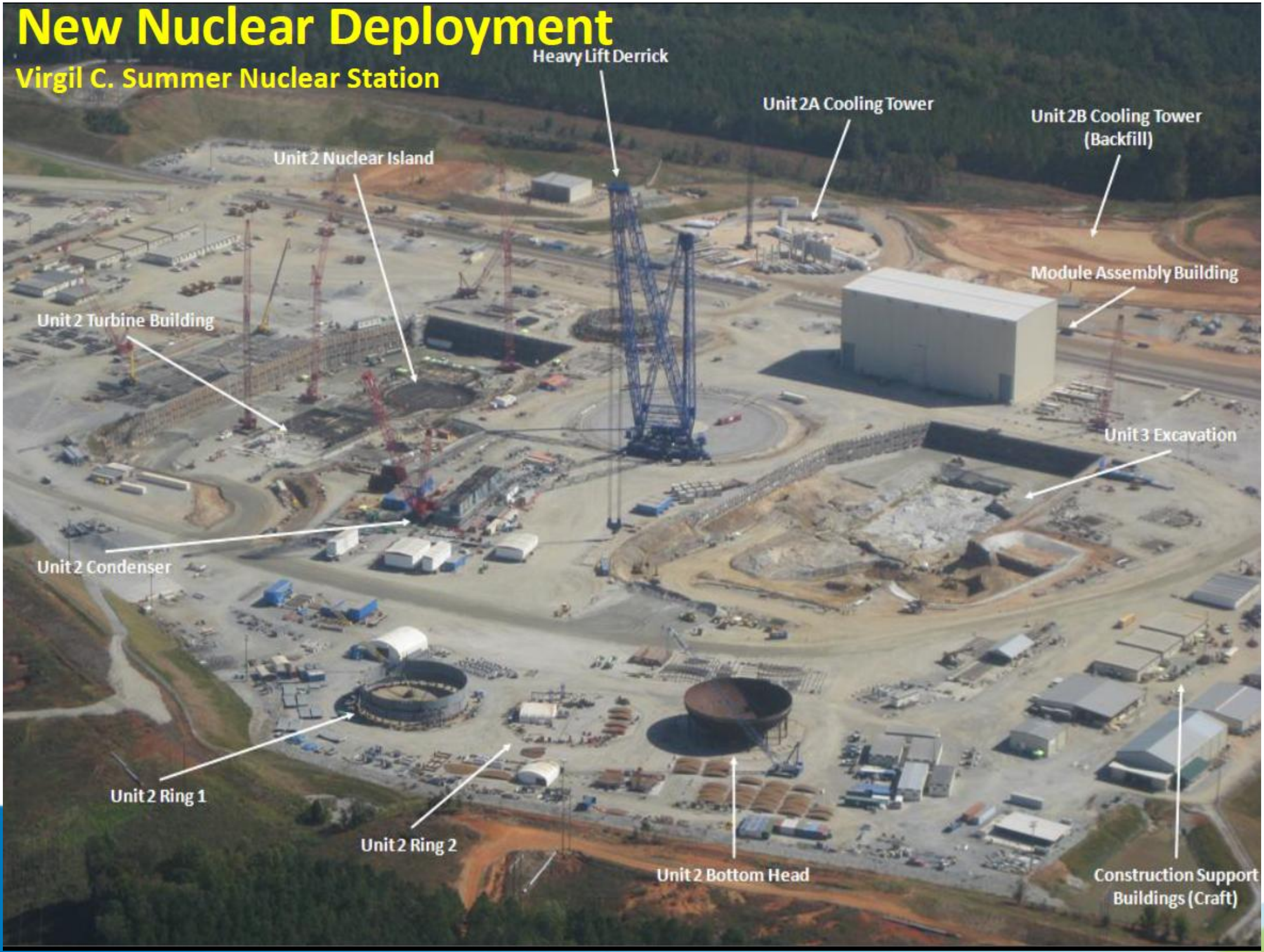
AP-1000

EUA

Vogtle 3&4 - Construction, January 31, 2013

AP-1000

EUA


New Nuclear Deployment
Virgil C. Summer Nuclear Station
Heavy Lift Derrick
Unit 2A Cooling Tower
Unit 2B Cooling Tower (Backfill)
Unit 2 Nuclear Island
Module Assembly Building
Unit 2 Turbine Building
Unit 3 Excavation
Unit 2 Condenser
Unit 2 Ring 1
Unit 2 Ring 2
Unit 2 Bottom Head
Construction Support Buildings (Craft)

EPR

EPR

competitividade pela escala e eficiência

SAFETY ABOVE ALL

- Designed to keep surrounding populations and environment safe in the event of internal accidents and external hazards (commercial plane crash, earthquake, etc.)
- Four independent safety systems that are physically separated, each capable of performing all safety functions
- Three leak-tight barriers between the radioactive nuclear fuel and the environment , the third of them being the steel and pre-stressed concrete containment with the capacity to withstand high pressure and temperature
- Advanced molten core retention in the unlikely event of a core meltdown

PROVEN TECHNOLOGY, CUTTING-EDGE DESIGN

- An evolutionary design built upon the most recent light water reactor technology in operation: the French N4 and German KONVOI models
- Features a fully computerized instrumentation & control (I&C) system that reduces the risk of human error and facilitates technical and operational support
- An axial economizer within each steam generator allows for higher steam pressure and improves plant efficiency

CONCEIVED WITH THE ENVIRONMENT IN MIND

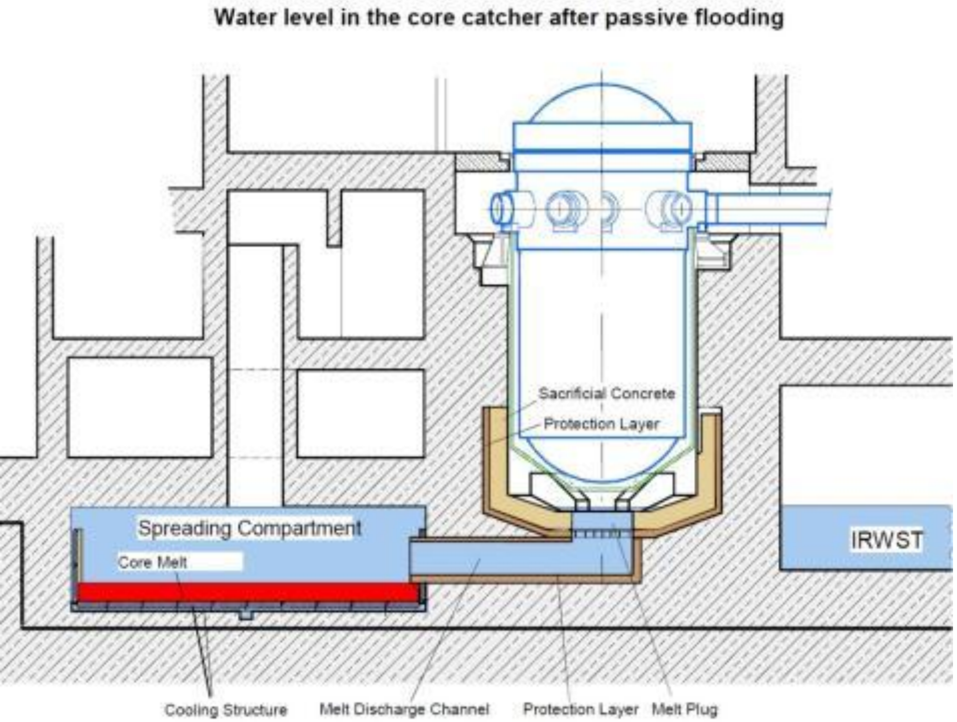
- Uranium consumption reduced by 15% per MWh produced
- Improved fuel management reduces generation of long-lived actinides by 10% per MWh*
- Maximized power output per site (1,650 MWe)
- Reduced water use thanks to thermal efficiency
- Capability to use mixed recycled oxide uranium (MOX) Collection doses reduced by 30% as compared to the best World Association of Nuclear Operators one-year median value.

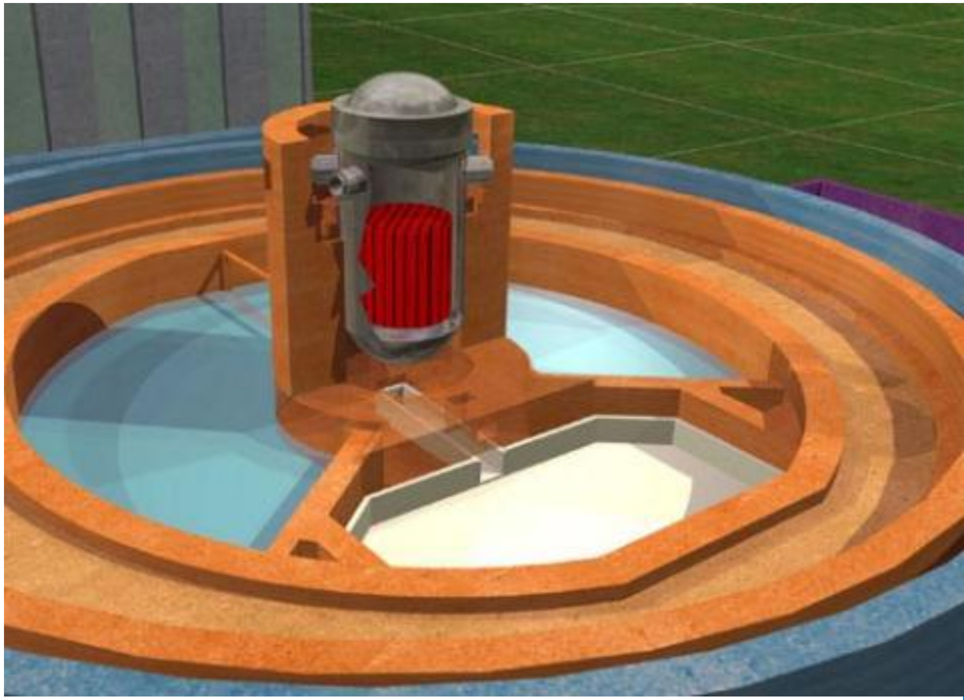
DISTINCTIVELY COMPETITIVE

- 20% savings on operation and maintenance costs thanks to EPR^{TM}'s high capacity and availability
- Up to 15% savings on uranium per MWh produced and more power per kilogram of uranium as compared with other designs
- higher availability than other designs, targeted at 92%
- designed to optimize capital expenditure and for high durability, with an expected 60-year operating life time

EPR

recuperador de “corium”





EPR


Oikiluoto


Flamanville

© EDF


Taishan

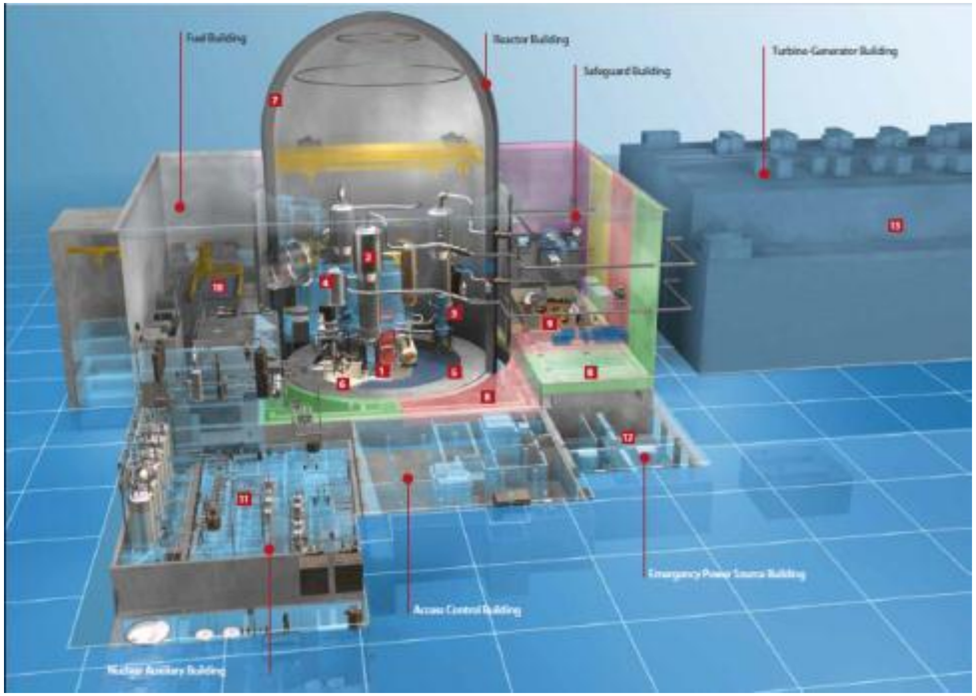

Hinckley Point

© EDF ENERGY

ATMEA

ATMEA

The mid-sized Generation III+ PWR you can rely on



Top-level safety as a Generation III^{+} plant

- Regulatory compliance: compatible worldwide including US, Europe, Japan
- Probabilities of core damage and of large radiological release a factor of 10 lower than conventional PWRs
- Clear separation between safety and operational systems
- 3 Emergency Power Supply Systems + 1 back up train + Diversified additional Alternative AC Power system (AAC)
- External hazards: protected against large commercial airplane crash, earthquake, flooding
- Long-term containment integrity against severe accidents kept by core catcher, passive hydrogen control capability

High operation performances by reliable and proven technologies

High thermal efficiency

- 10% of generation cost and fuel consumption savings compared to Generation-II PWRs
- Realized by efficient steam generator design with economizer, state-of-the-art turbine technologies, etc.

High plant availability

- Less than 16 days for normal refueling outage
- On-line maintenance capability
- Accessible reactor building design during operation
- Reliable and proven technologies integrating AREVA and Mitsubishi experiences

Operation flexibility

- Flexible 12 to 24-month operation cycle length keeping an economical fuel consumption
- Extended load-follow and frequency control capabilities
- MOX loading capability up to 100%

Flexibility for site and grid conditions

- 1100 – 1150 MW (net) compatible with almost every grid
- Design available for high seismic area
- Design available for 50/60Hz and various heat sink conditions

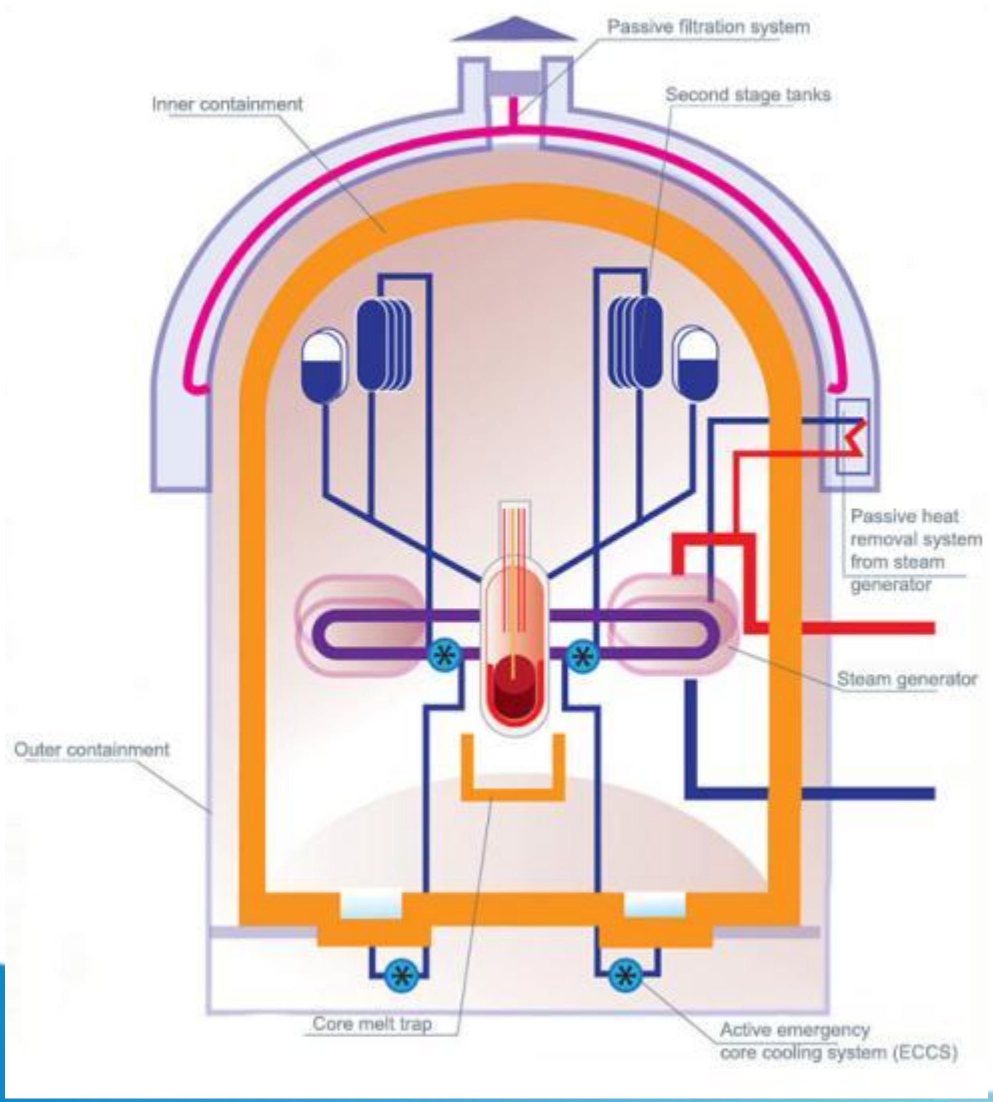
Relief of people around site area

- No emergency planning (evacuation, etc.) required
- Protection against severe accidents and air plane crash
- Less waste, less impact for environment

AES 2006

AES-2006

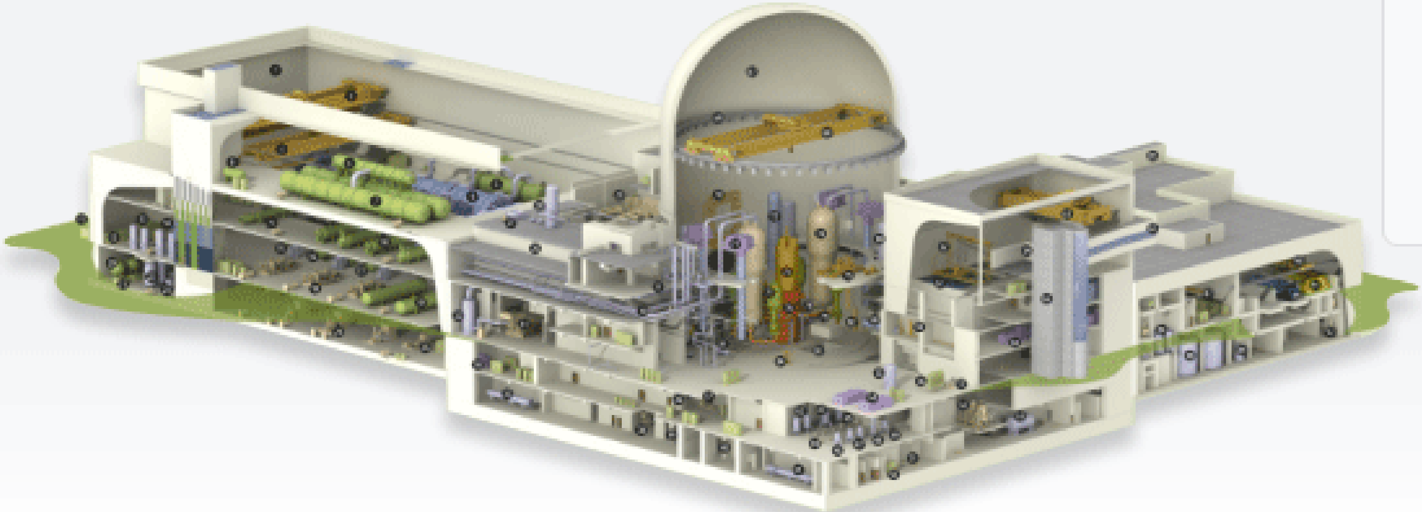
modernos sistemas de segurança

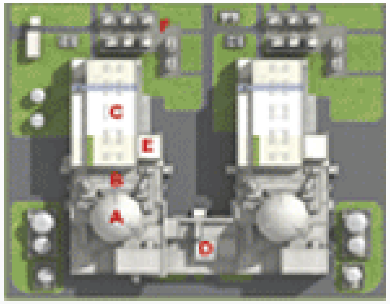


AES-2006

Kudankulan (India)

Advanced Power Reactor 1400





A. Containnent Building
B. Acutally Building
C. Turbins Building
D. Containnent Building
E. Acutally Building
F. Turbins Building

Advanced Design

- 4-train direct vessel injection safety system and fluidic device in safety injection tank
- In-containment refueling water storage tank
- Digital I&C and operator-friendly man-machine interface

Enhanced Safety

- Adoption of proven & evolutionary technologies
- Reduced core damage & containment failure frequency
- Reinforced seismic design basis
- Improved severe accident mitigation system

Improved Cost Effectiveness

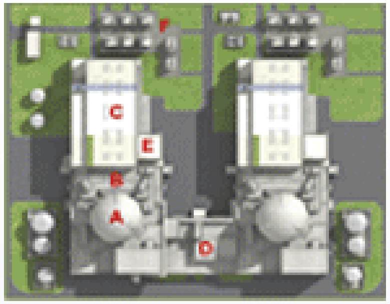
- Extended plant design lifetime
- Reduced operation & construction cost
- Minimum site boundary via plant general arrangement optimization
- State-of-the-art construction technologies

Convenient Operation & Maintenance

- Extended operator response time
- Reduced occupational exposure
- Convenient facilities for improved maintenance & inspection

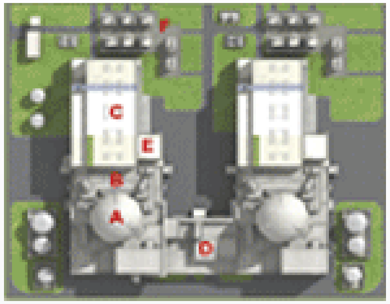
Advanced Power Reactor
1400

Shin-Kori 1 &2 (Coréia do Sul)



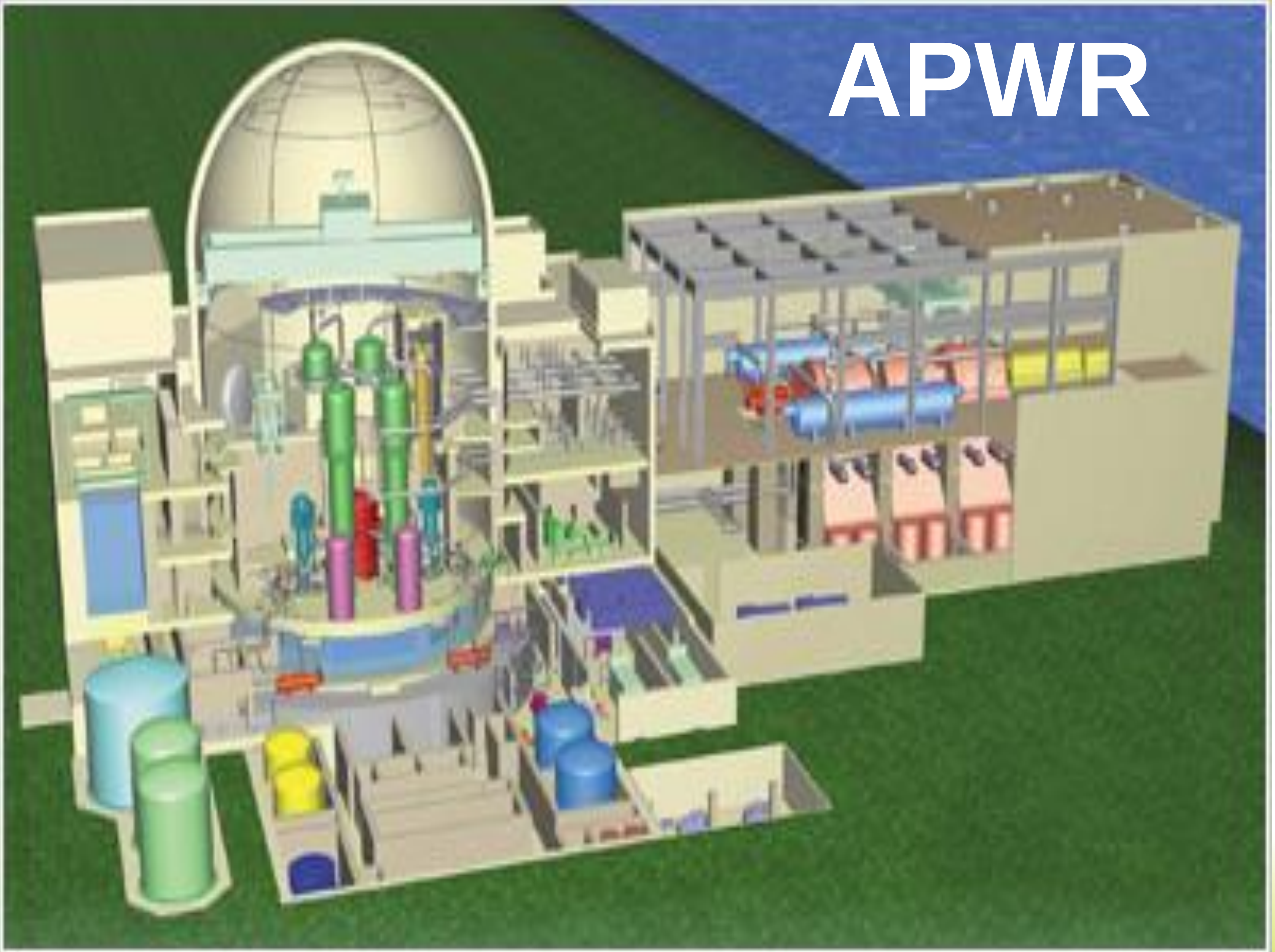
A. Containnent Building
B. Acutally Building
C. Turbins Building
D. Containnent Building
E. Acutally Building
F. Turbins Building

Advanced Power Reactor
1400



Construction Site of Unit 1, Barakah Nuclear Power Plant, UAE. (Photo: ENEC)

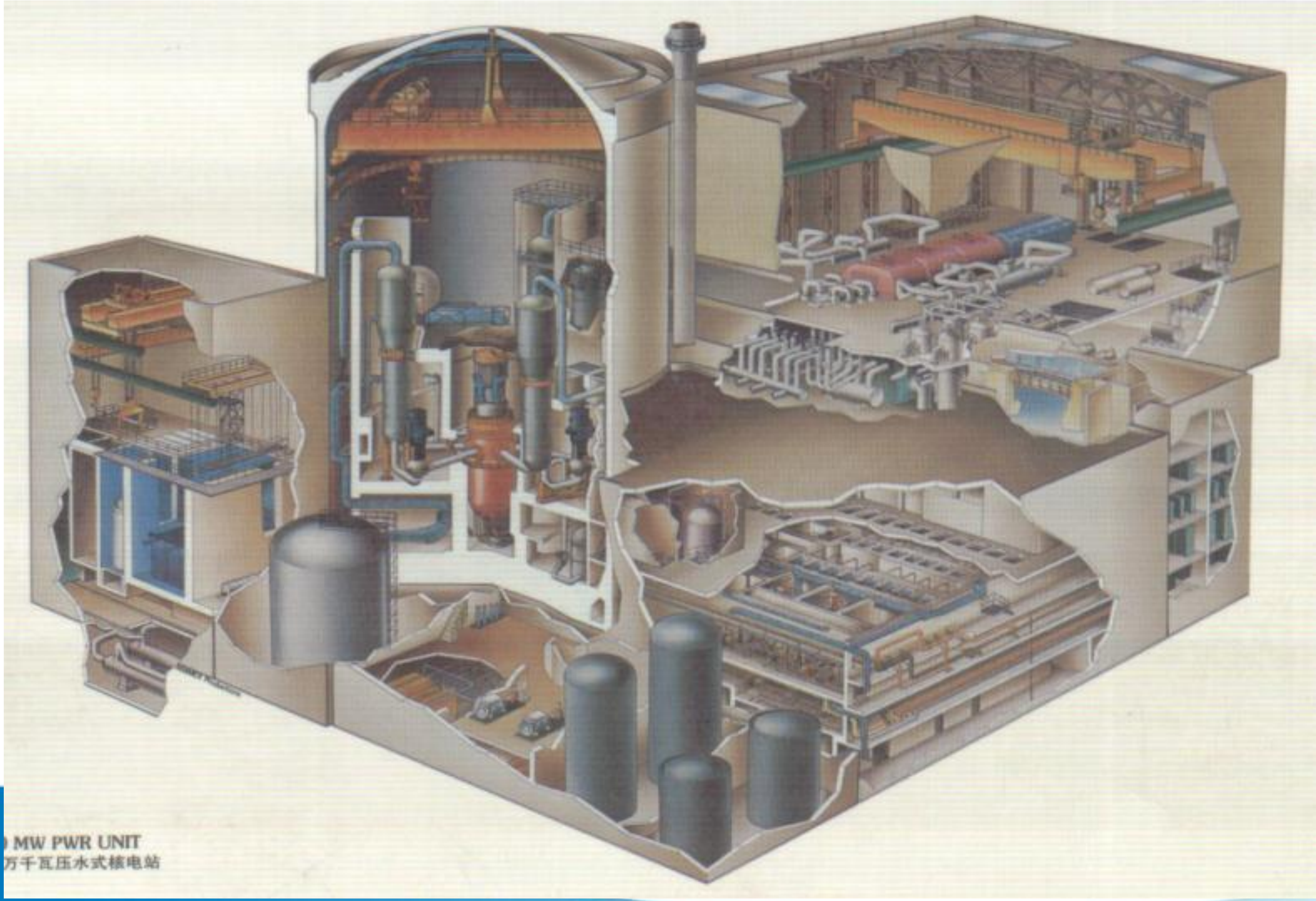
APWR



CPR-1000

CPR-1000

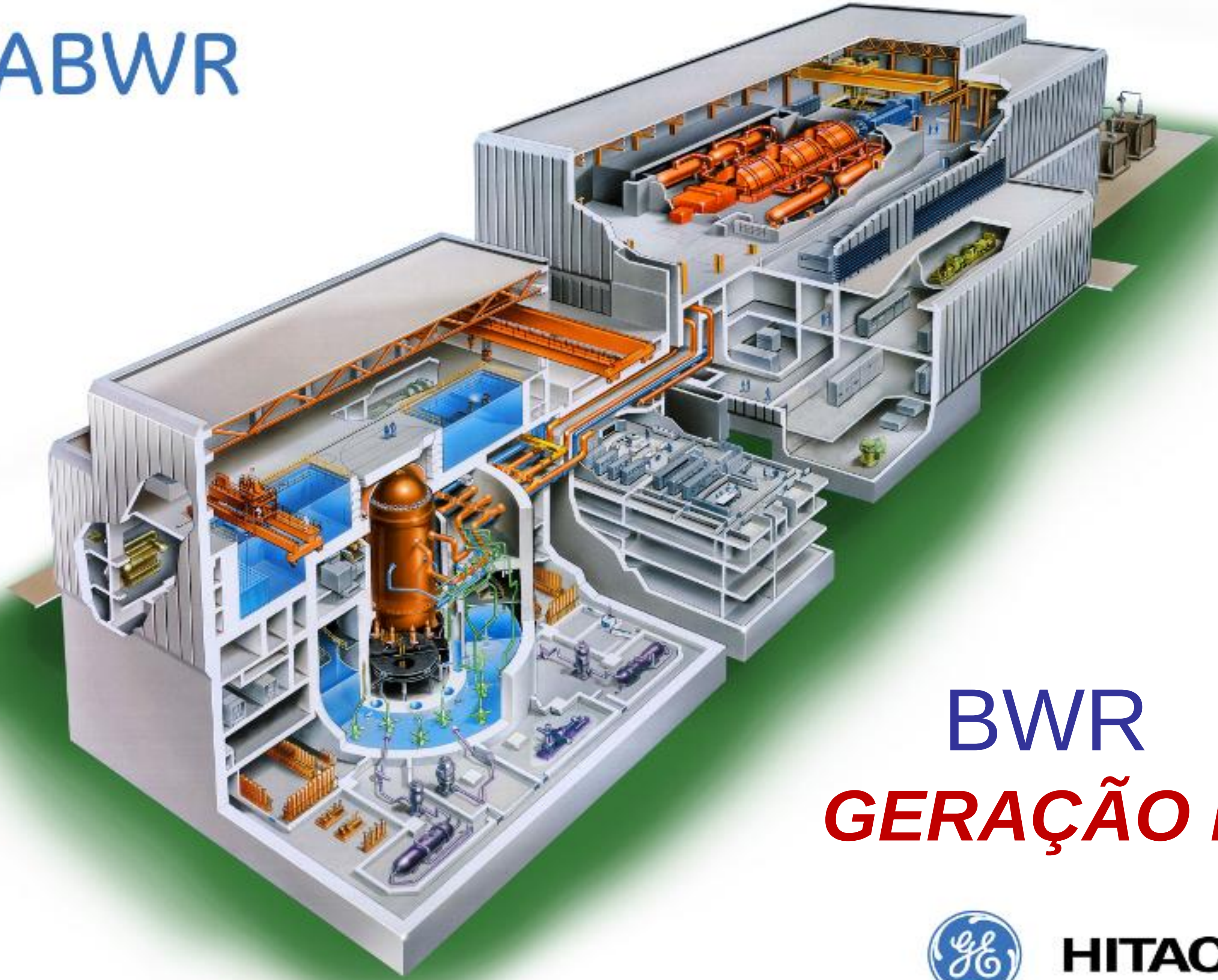
geração II+



CAP-1400

geração III+

ABWR



BWR

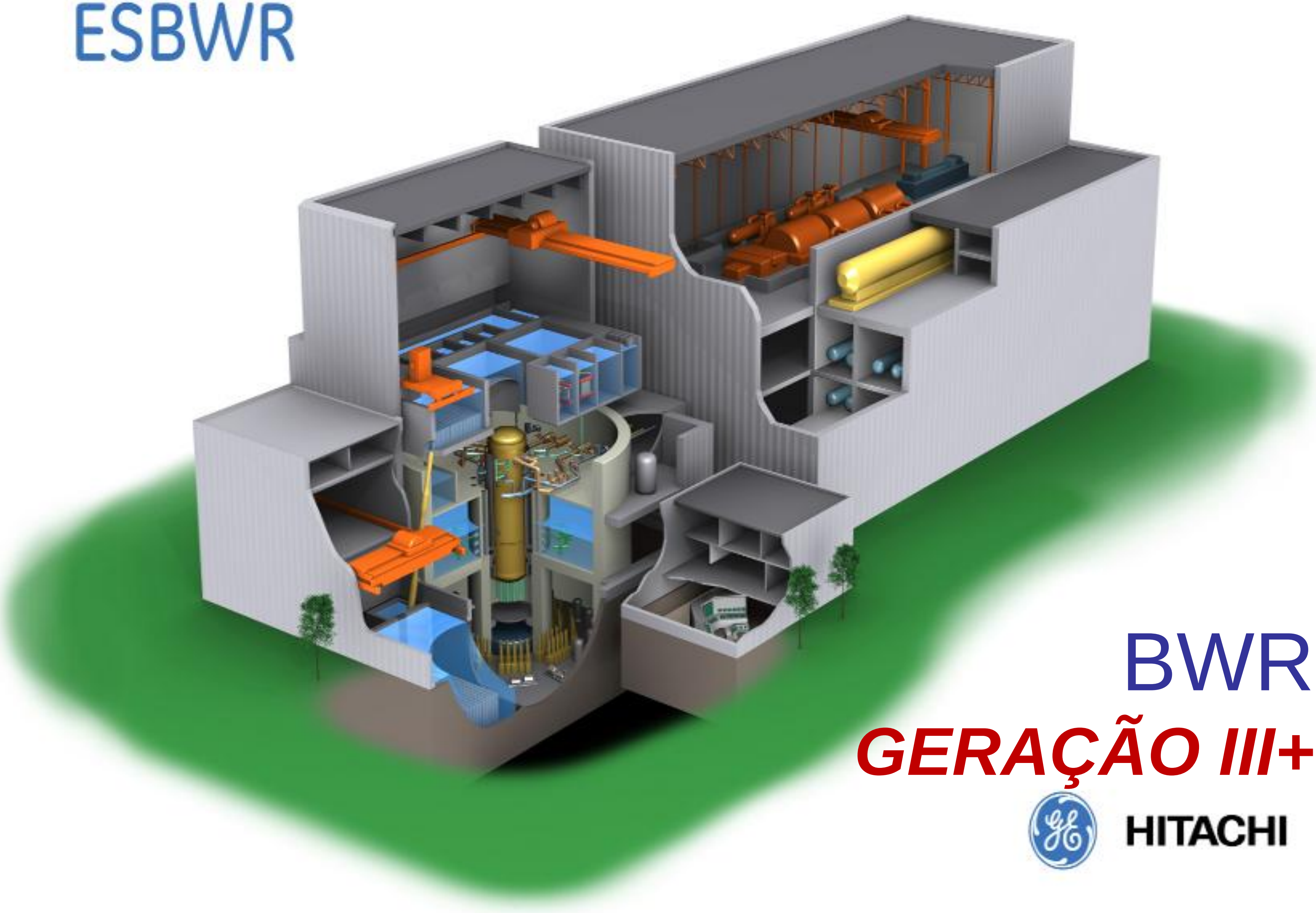
GERAÇÃO III

GE HITACHI

ABWR

Shika (Japão)

ESBWR



BWR

GERAÇÃO III+

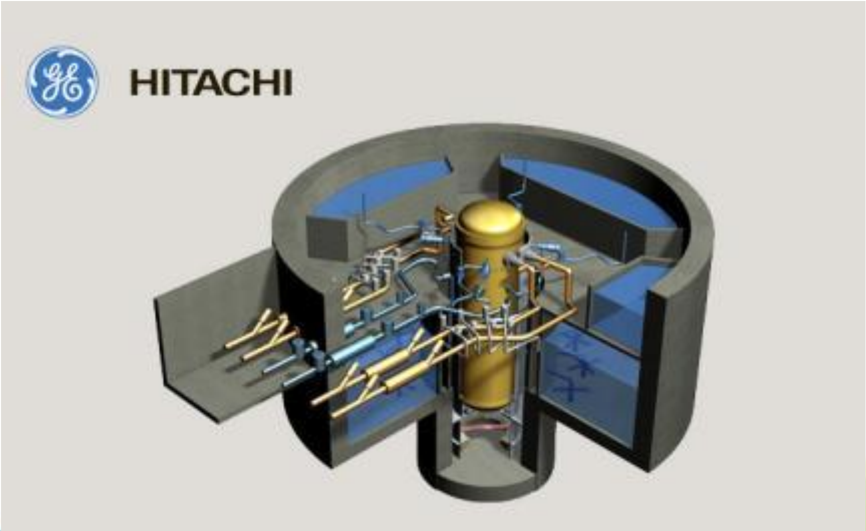
HITACHI

ESBWR

resfriamento passivo / rapidez na construção

Features & Benefits

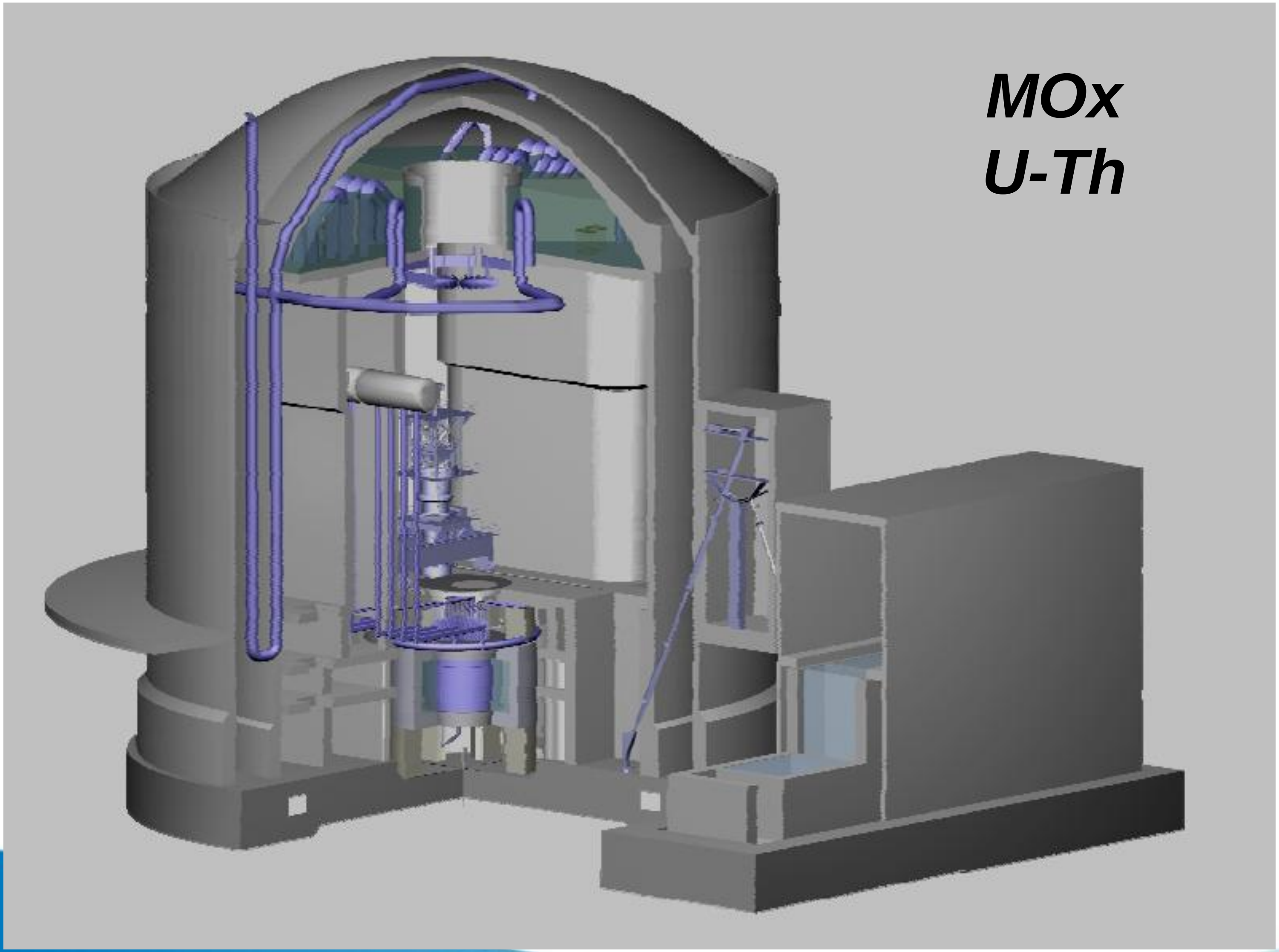
- Simplified design builds on proven technology, increasing fuel efficiency yet decreasing overall operation and maintenance costs
- Sophisticated control systems – fully digital, providing reliable and accurate plant monitoring, control, and diagnostics
- Enhanced safety compliance with three layers of protection during an accident and the highest regulatory ratings
- Expedited, economical construction schedule due to pre-licensed design and standardized modules
- Experienced global supply chain team with referenced construction schedule of 36 months
- Environmentally friendly with nearly zero greenhouse gas emissions – equal to taking 1.5 million cars off the road
- Currently in the U.S. Design Certification process



Advanced CANDU Reactor

Image courtesy of AECL

APHWR-300



MOx
U-Th

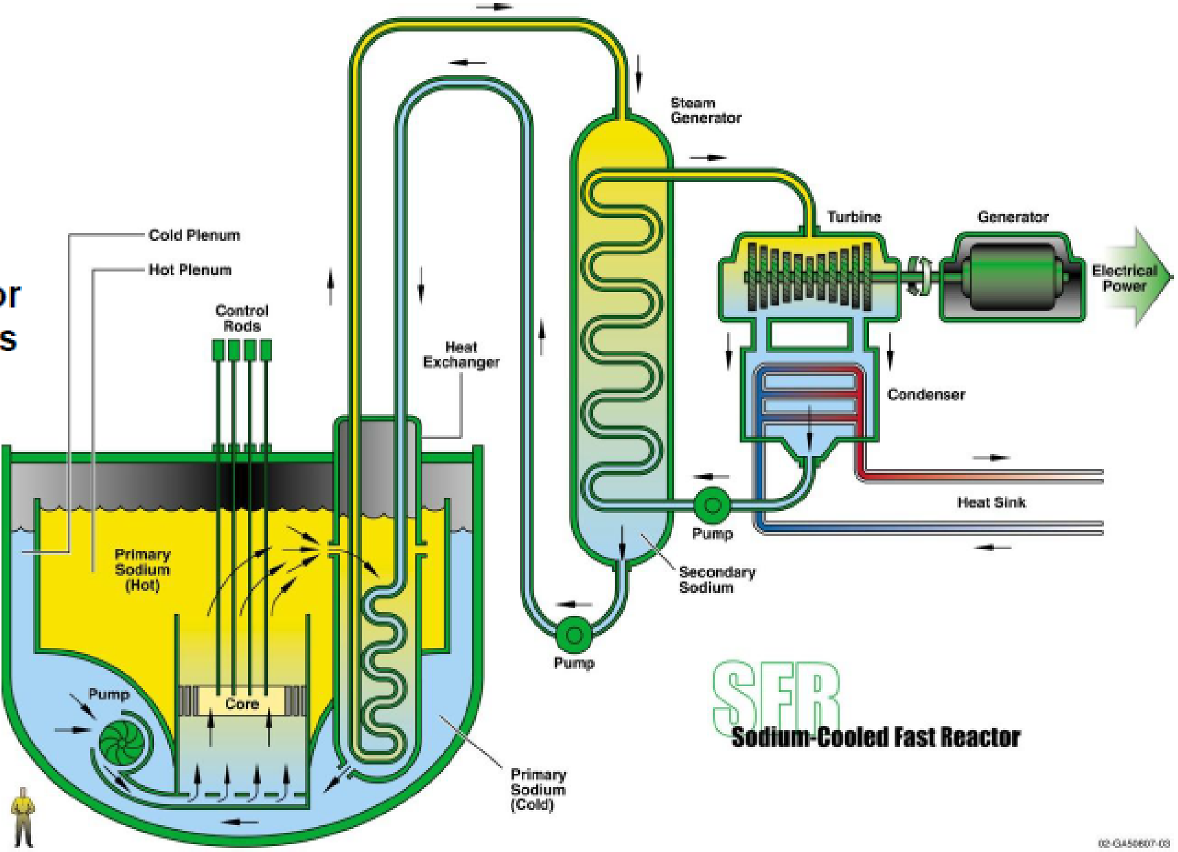
Sodium-Cooled Fast Reactor (SFR)

Characteristics

- Sodium coolant
- 550C outlet temperature
- 600-1500 MWe large size, or
- 300-600 MWe intermediate size
- 50 MWe small module option
- Metal fuel with pyroprocessing or MOX fuel with advanced aqueous separation

Benefits

- High thermal efficiency
- Consumption of LWR actinides
- Efficient fissile material generation



China's experimental fast neutron reactor begins generating power

21/07/2011

BN-800 em construção na Rússia

Construction Site of the BN-800 Fast Reactor at the Beloyarsk Nuclear Power Station, Russian Federation. (Photo: ROSATOM)

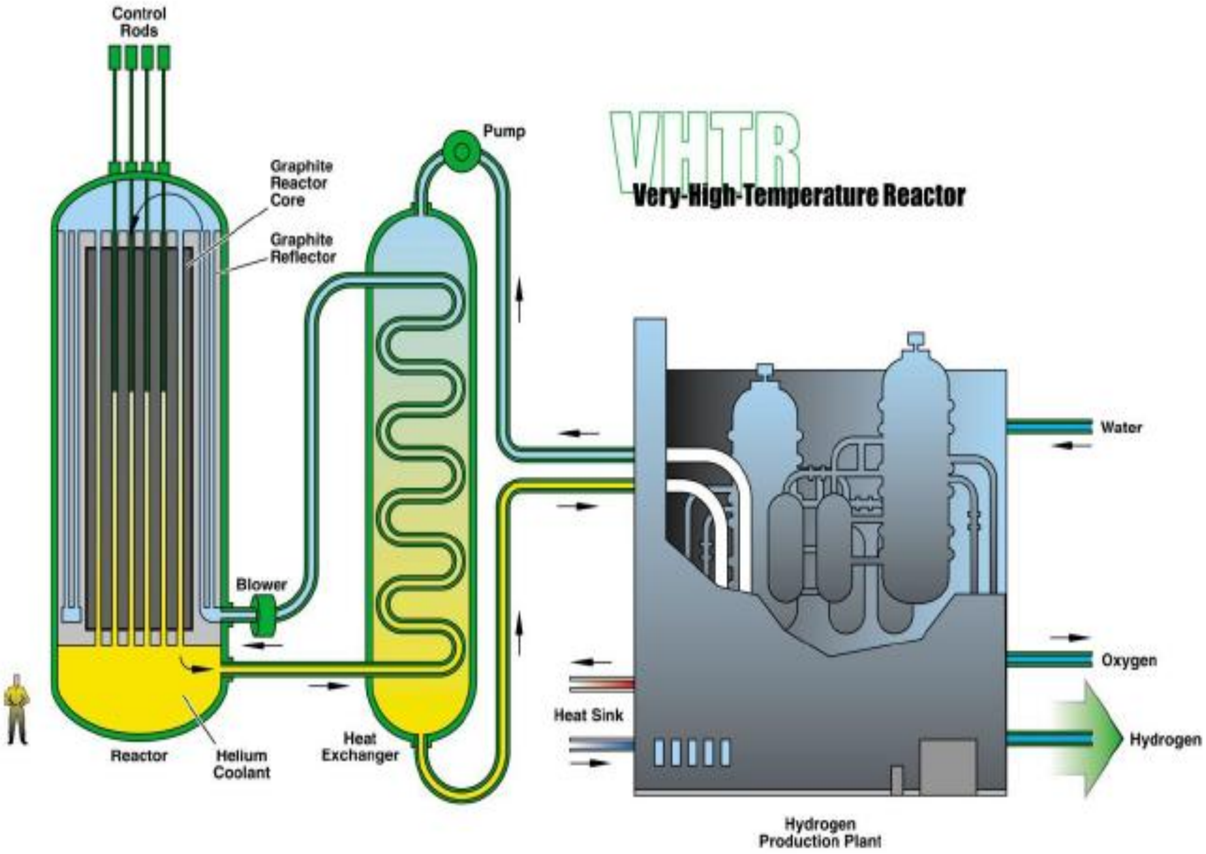
Very-High-Temperature Reactor (VHTR)

Characteristics

- He coolant
- >900C outlet temperature
- 250 MWe
- Coated particle fuel in either pebble bed or prismatic fuel

Benefits

- Hydrogen production
- Process heat applications
- High degree of passive safety
- High thermal efficiency option



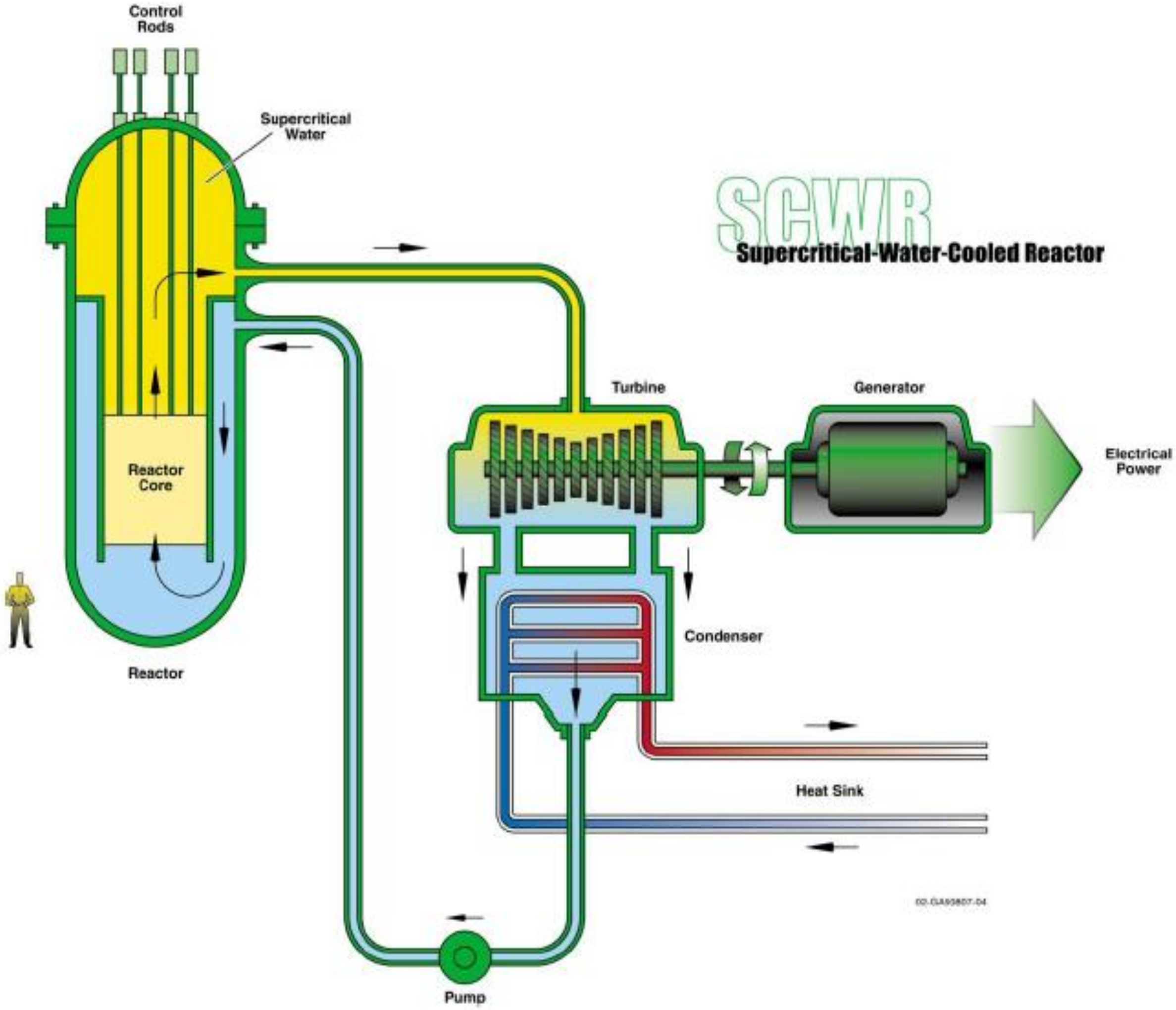
Supercritical-Water-Cooled Reactor (SCWR)

Characteristics

- Water coolant above supercritical conditions (374C, 22.1 MPa)
- 510-625C outlet temperature
- 1500 MWe
- Pressure tube or pressure vessel options
- Simplified balance of plant

Benefits

- Efficiency near 45% with excellent economics
- Leverages the current experience in operating fossil-fueled supercritical steam plants
- Configurable as a fast- or thermal-spectrum core



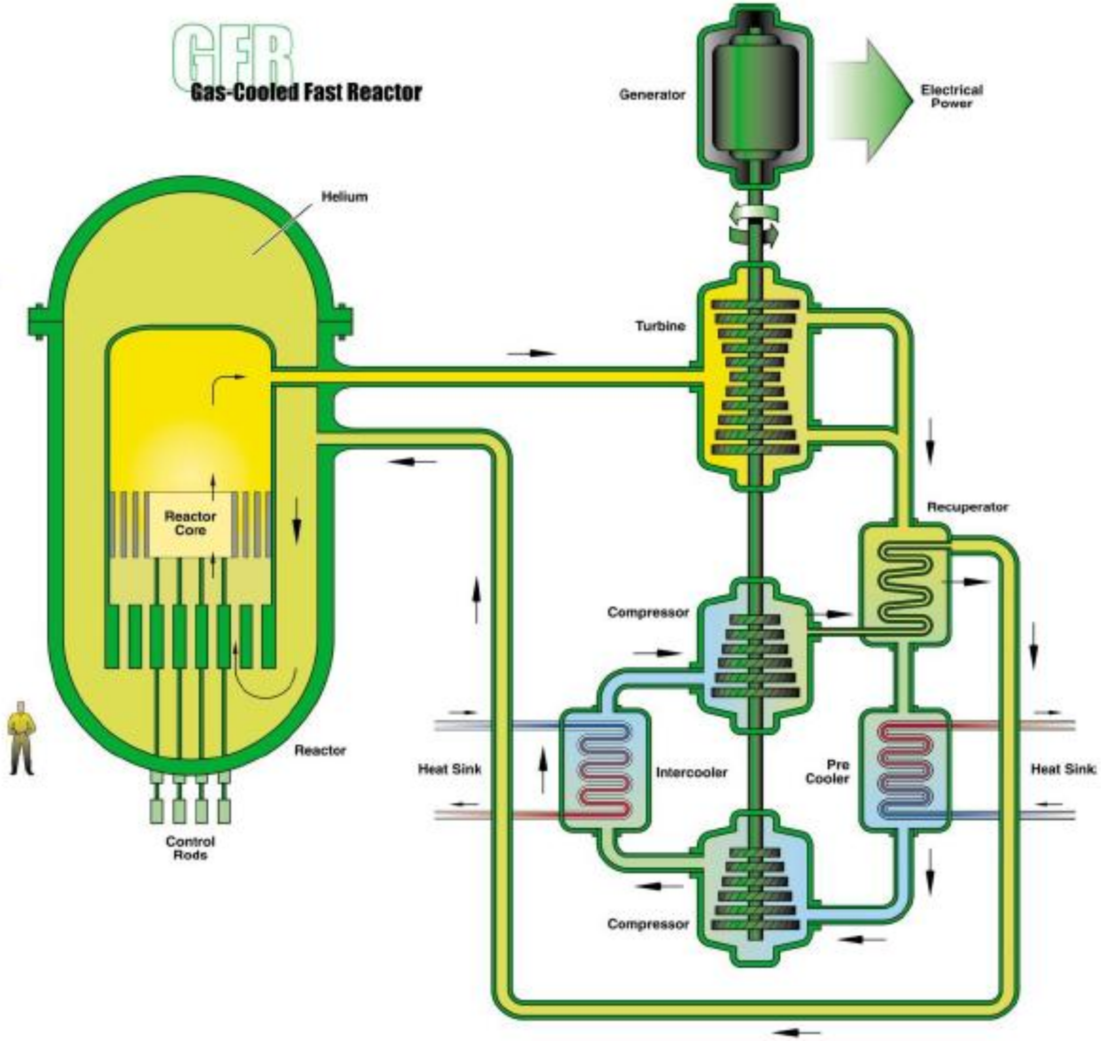
Gas-Cooled Fast Reactor (GFR)

Characteristics

- **He coolant**
- **850C outlet temperature**
- **Direct gas-turbine cycle or supercritical CO2 cycle with optional combined cycles**
- **2400 MWth / 1100 MWe**
- **Several fuel options**
  - **Carbide in plates or pins**
  - **Nitride**
  - **Oxide**

Benefits

- **High efficiency**
- **Waste minimization and efficient use of uranium resources**



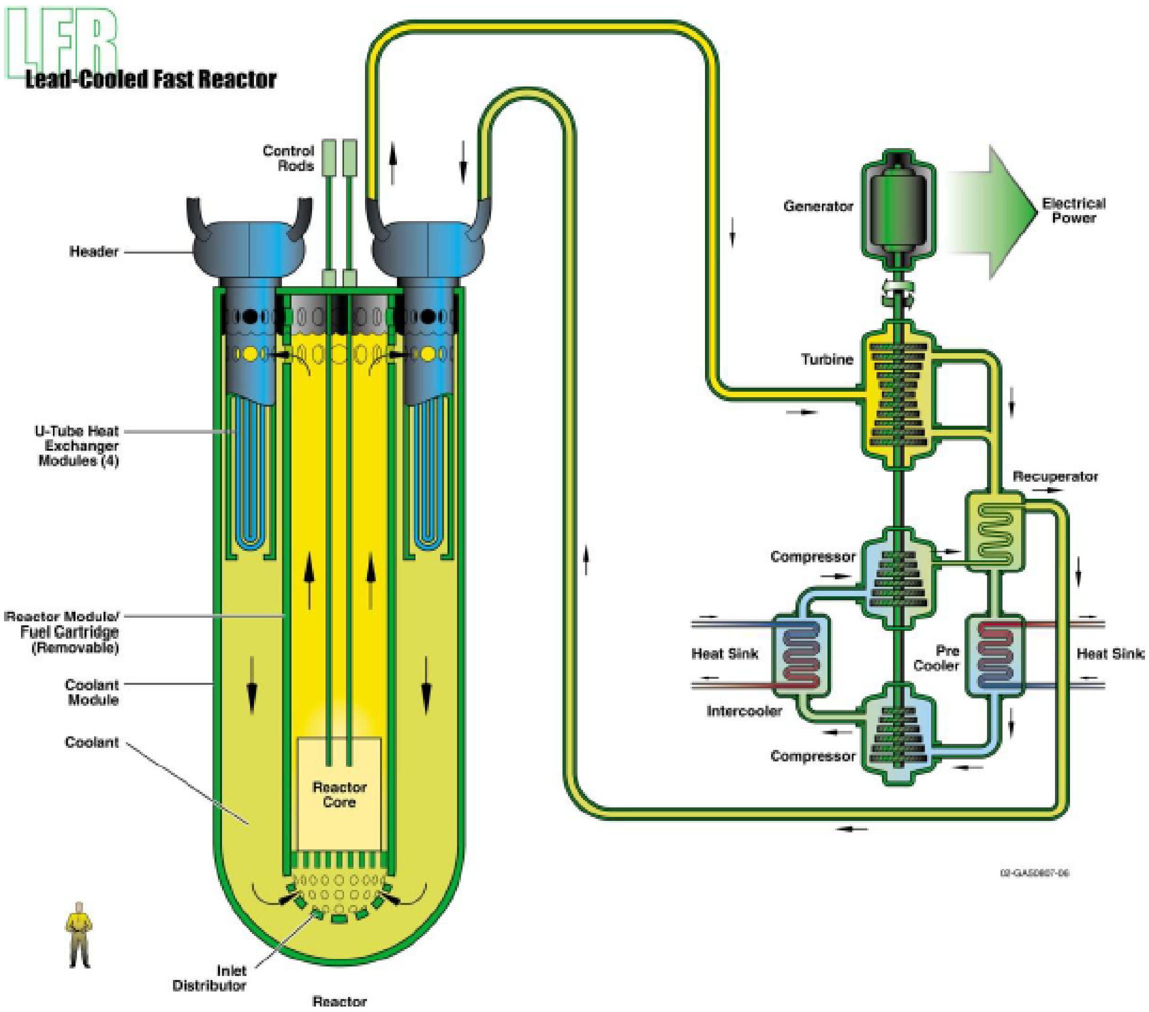
Lead-Cooled Fast Reactor (LFR)

Characteristics

- Pb or Pb/Bi coolant
- 550C to 800C outlet temperature
- Small transportable system 50-150 MWe, and
- Larger station 300-1200 MWe
- 15–30 year core life option

Benefits

- Distributed electricity generation
- Hydrogen and potable water
- Replaceable core for regional fuel processing
- High degree of passive safety
- Proliferation resistance through long-life core



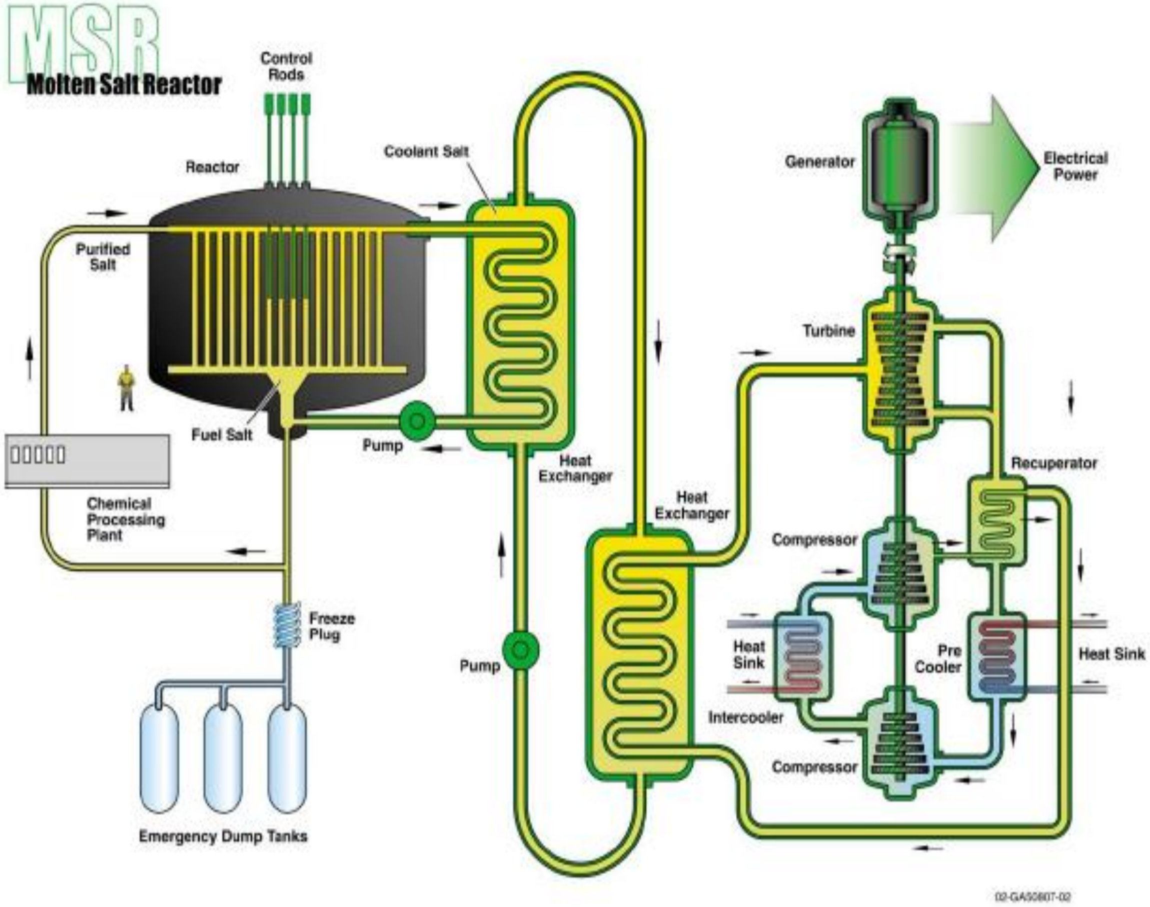
Molten Salt Reactor (MSR)

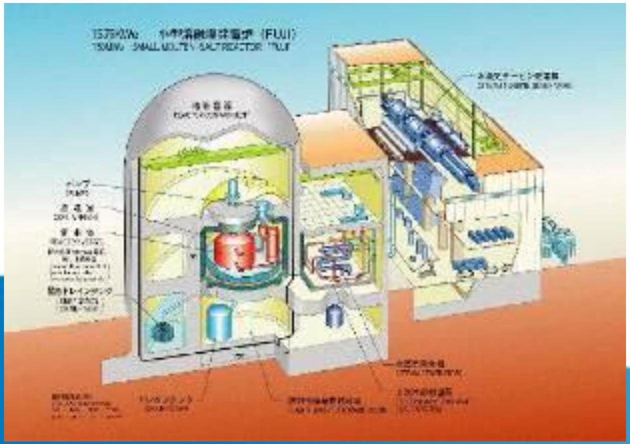
Characteristics

- Fuel is liquid fluorides of U and Pu with Li, Be, Na and other fluorides
- 700–800C outlet temperature
- 1000 MWe
- Low pressure (<0.5 MPa)

Benefits

- Waste minimization
- Avoids fuel development
- Proliferation resistance through low fissile material inventory

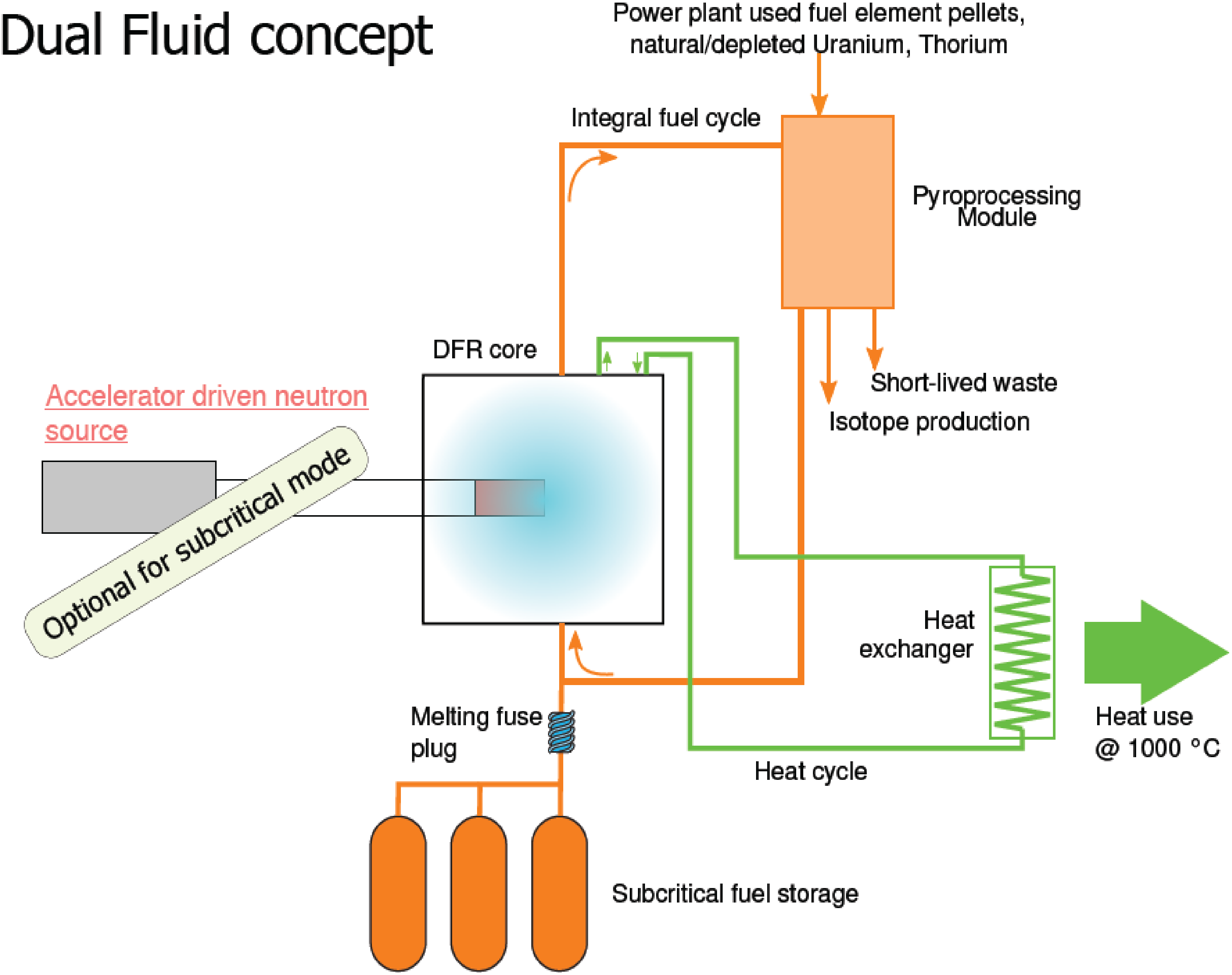




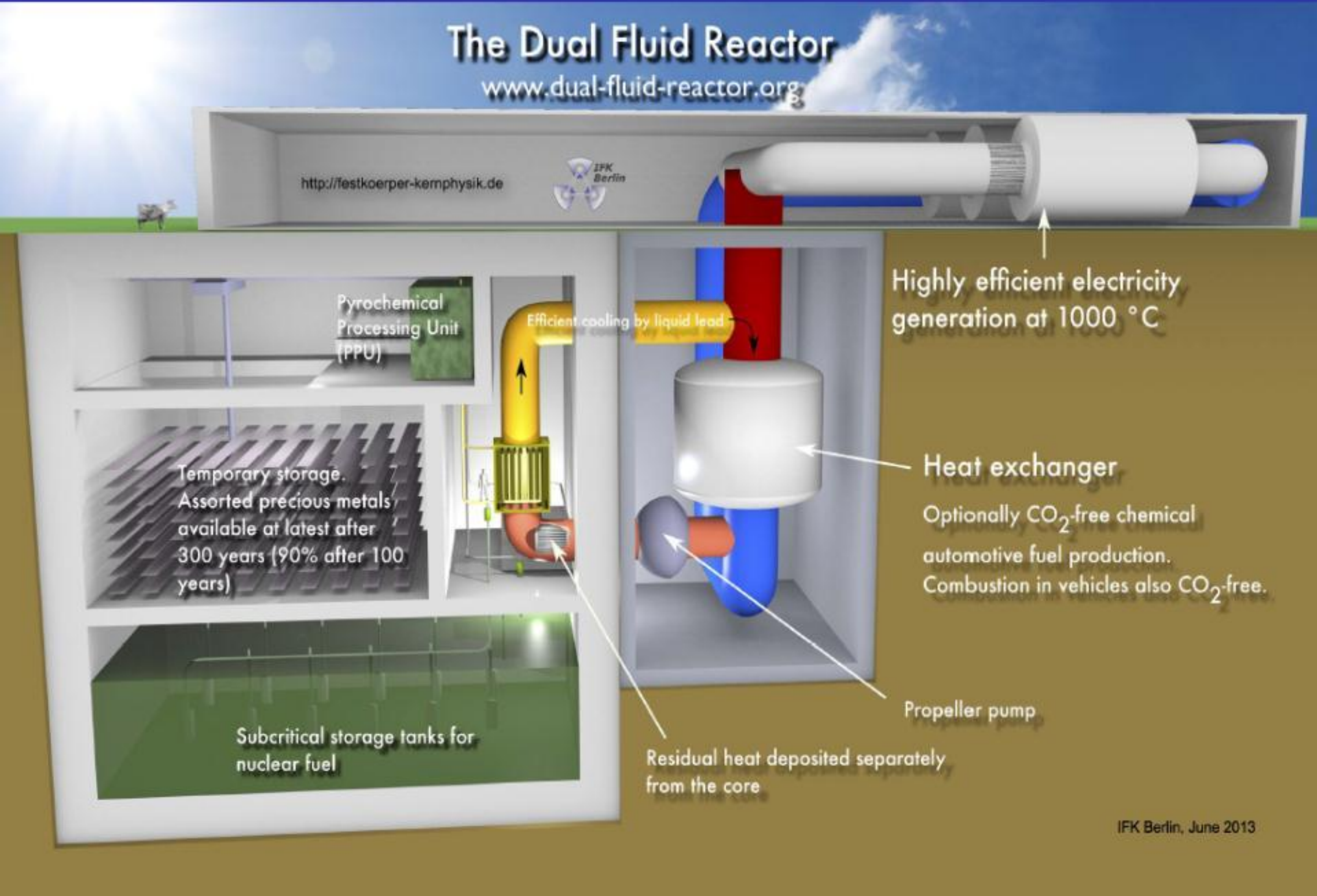
IThEMS MSR FUJI

The Dual Fluid Reactor (DFR)

The Dual Fluid concept

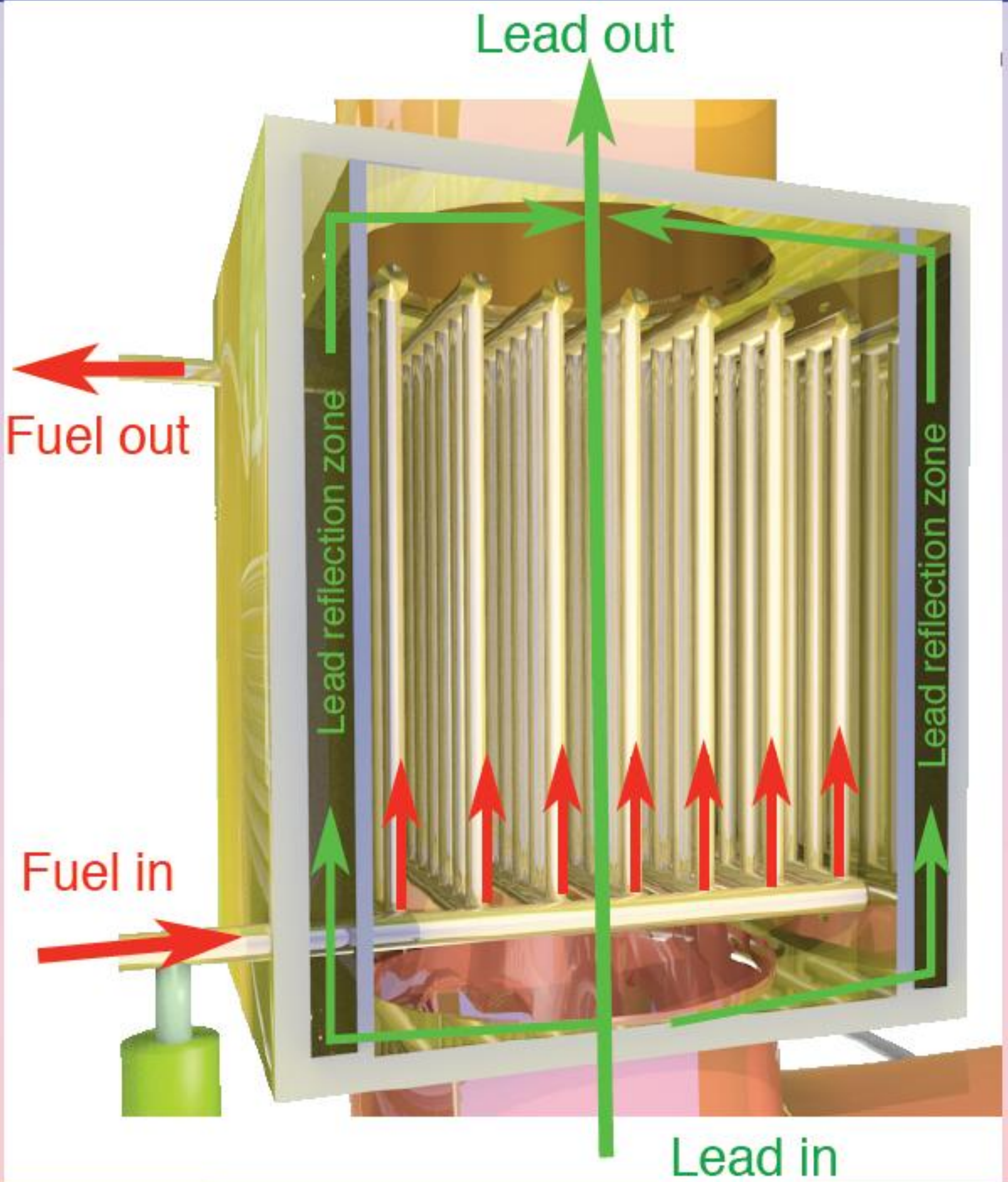


The Dual Fluid Reactor (DFR)



IFK Berlin, June 2013

The Dual Fluid Reactor (DFR)

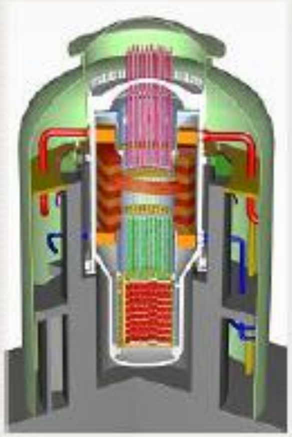


SMR avançados

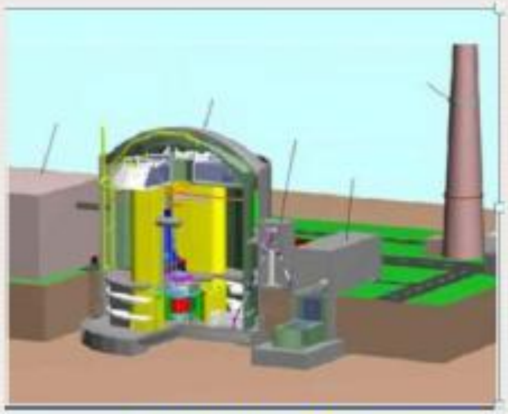
(incluindo PWRs integrados e modulares)

SMR inovadores

(incluindo PWRs integrados e modulares)



IMR
Japan



AHWR300-LEU
India

GT-MHR
USA

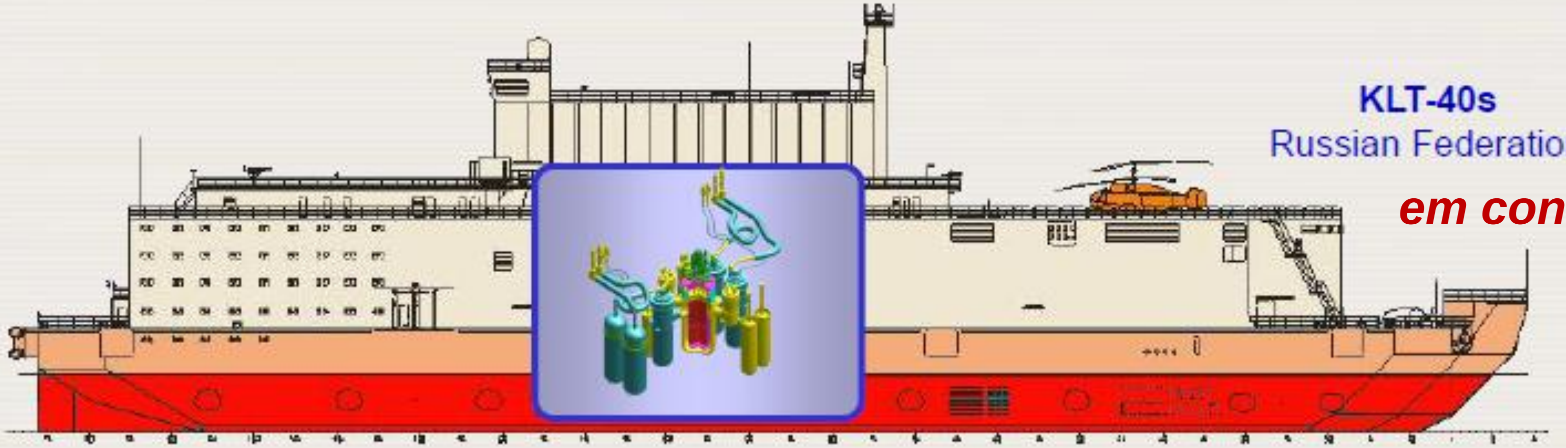
PRISM
USA

EM^2
USA

PBMR
South Africa

SMR convertidos/modificados

(usinas flutuantes)



KLT-40s
Russian Federation

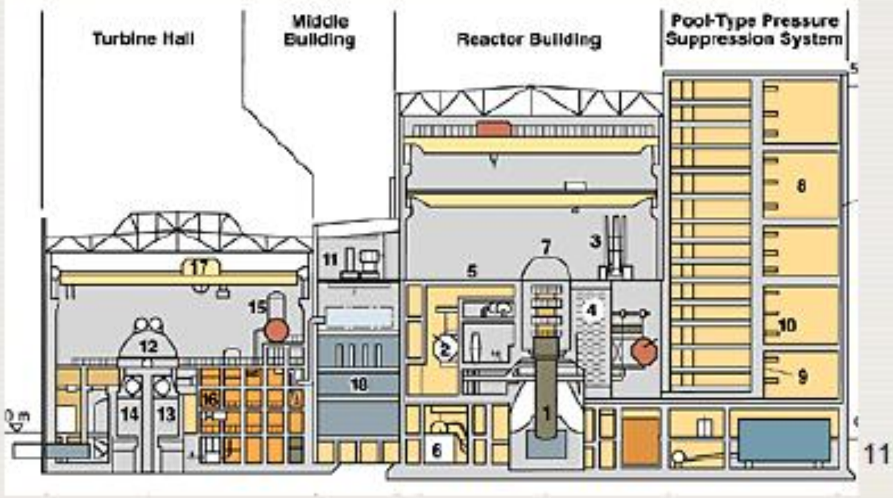
em construção

SVBR-100
Russian Federation

SMR “convencionais”

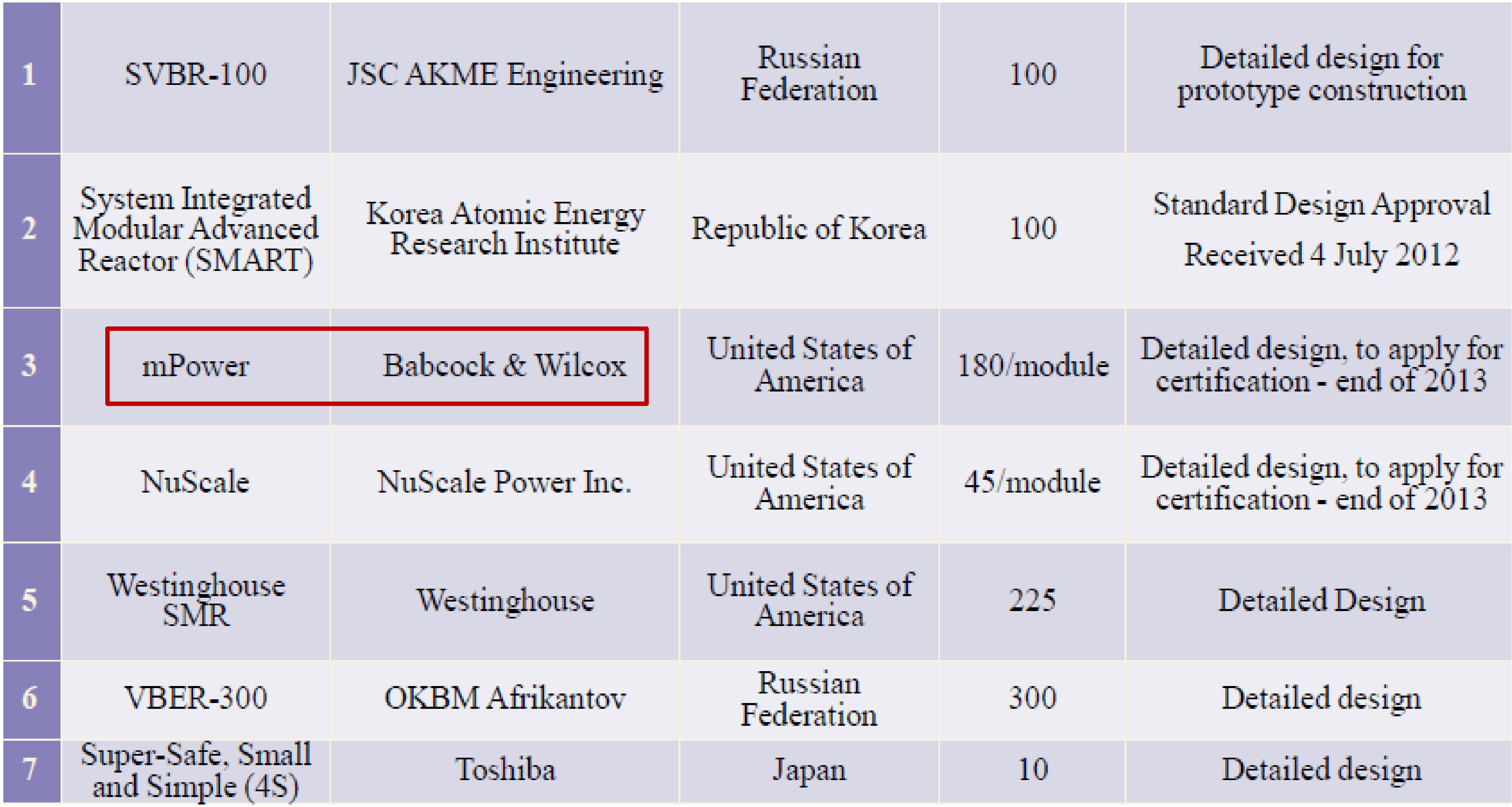
CNP-300
China, Peoples Republic of

PHWR-220, 540, & 700
India



VVER-440,
Russian Federation

SMRs com projeto mais adiantado

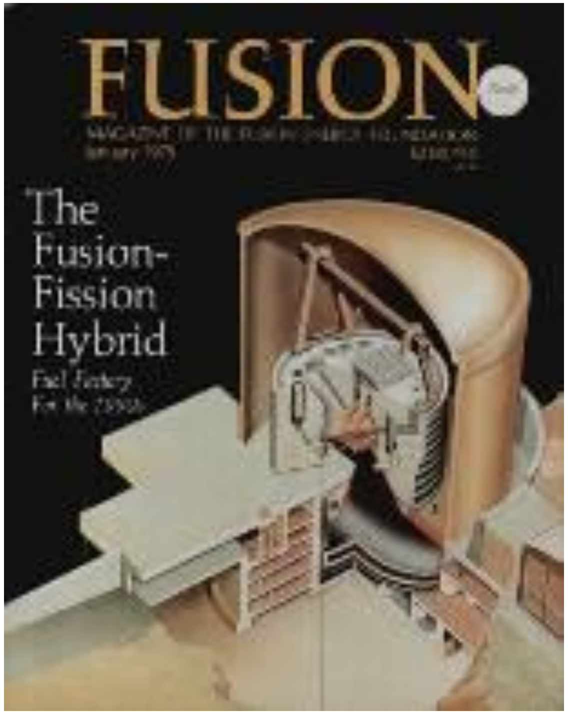


1	SVBR-100	JSC AKME Engineering	Russian Federation	100	Detailed design for prototype construction
2	System Integrated Modular Advanced Reactor (SMART)	Korea Atomic Energy Research Institute	Republic of Korea	100	Standard Design Approval Received 4 July 2012
3	mPower	Babcock & Wilcox	United States of America	180/module	Detailed design, to apply for certification - end of 2013
4	NuScale	NuScale Power Inc.	United States of America	45/module	Detailed design, to apply for certification - end of 2013
5	Westinghouse SMR	Westinghouse	United States of America	225	Detailed Design
6	VBER-300	OKBM Afrikantov	Russian Federation	300	Detailed design
7	Super-Safe, Small and Simple (4S)	Toshiba	Japan	10	Detailed design

ITER

International Thermonuclear Experimental Reactor - (ITER)

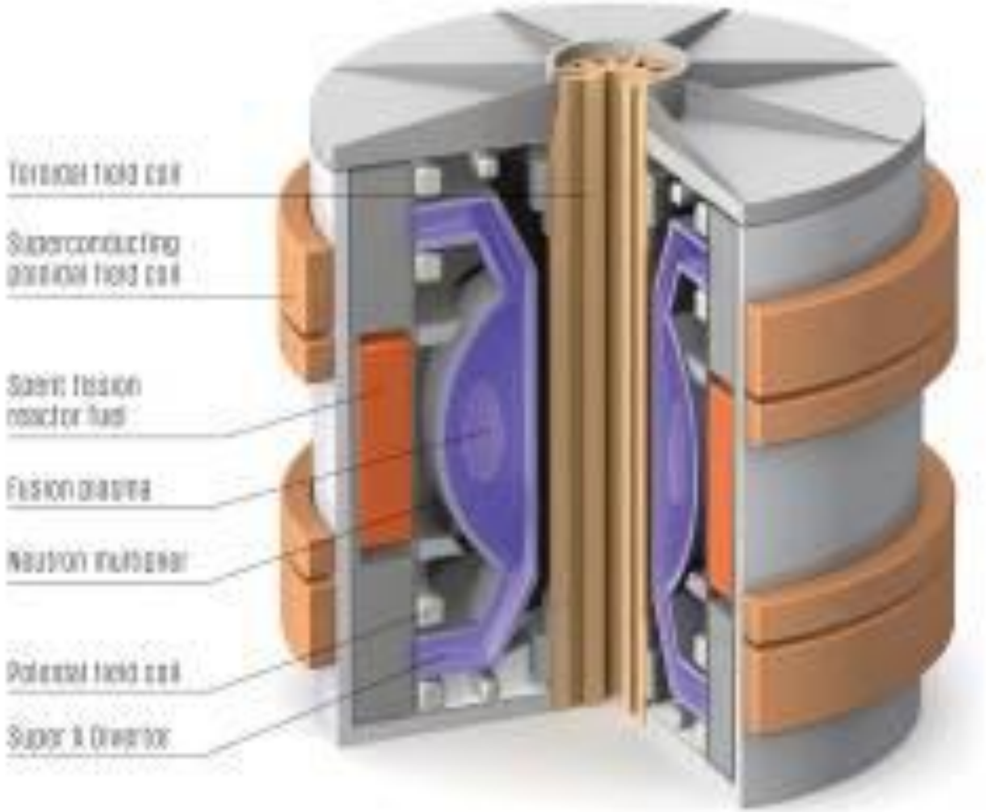
500 MWe


FUSION

The Fusion-Fission Hybrid

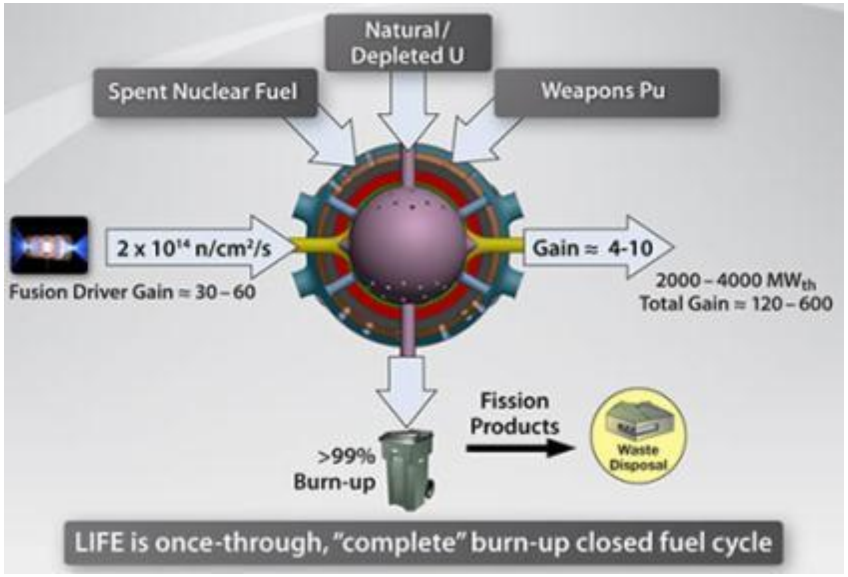
Fuel Factory

Reatores Híbridos fusão-fissão

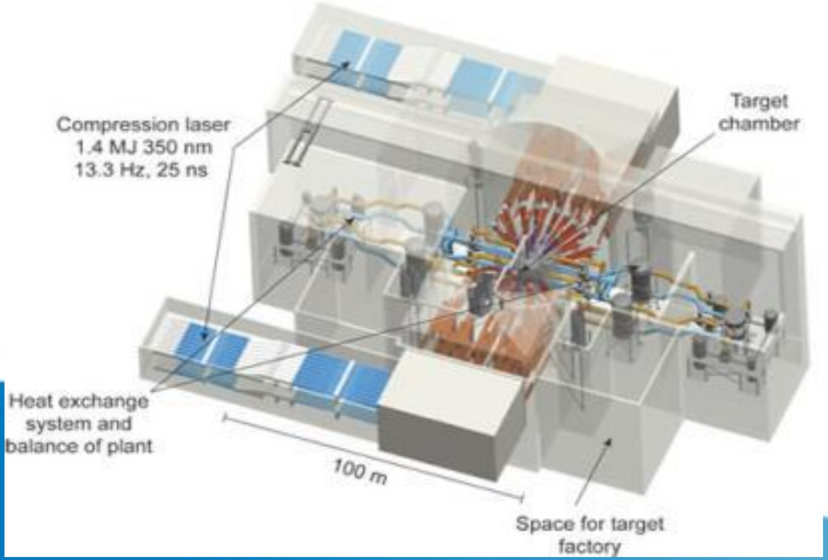


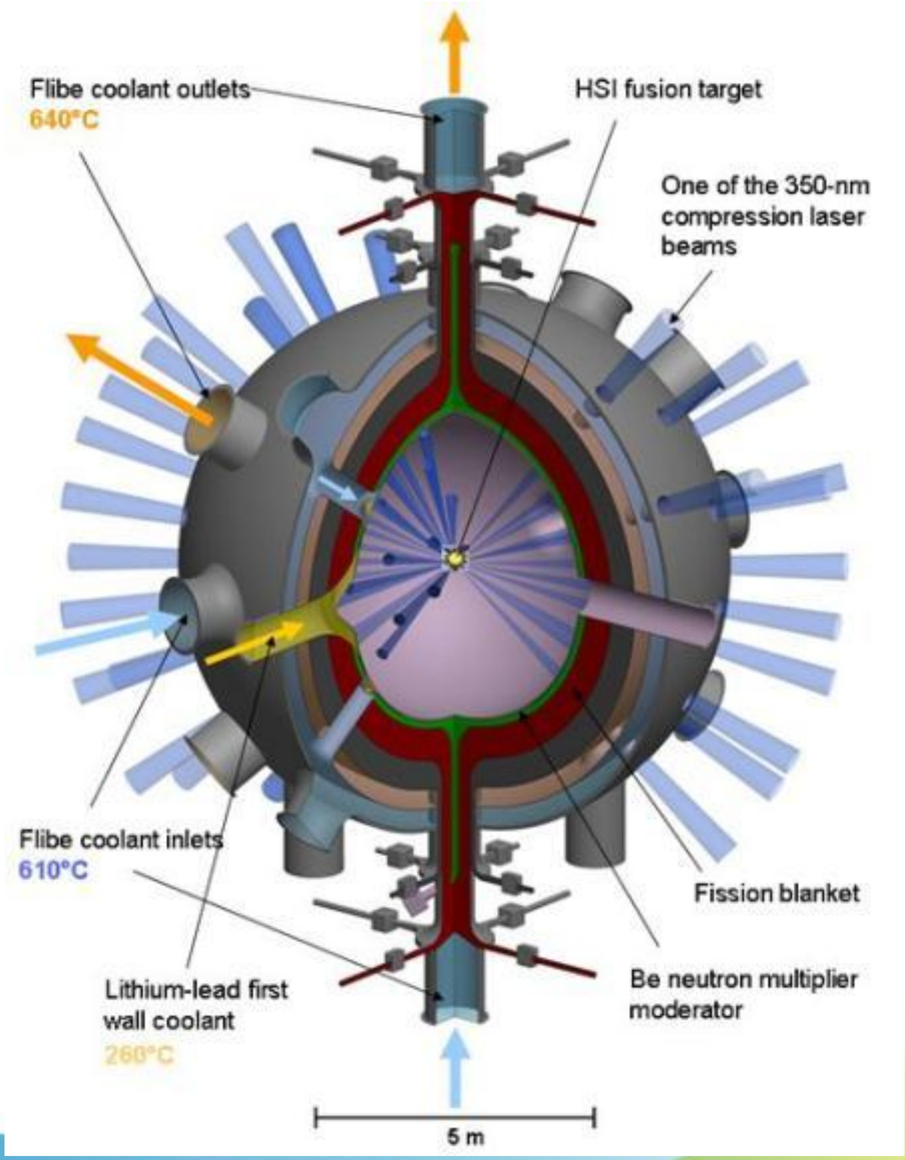
Super X Divertor (Tokamak de Transmutação)

Laser Inertial Fusion/Fission Experiment (LIFE)
Lawrence Livermore National Laboratory



LIFE is once-through, "complete" burn-up closed fuel cycle





Futuro Tecnológico da Geração Elétrica Nuclear

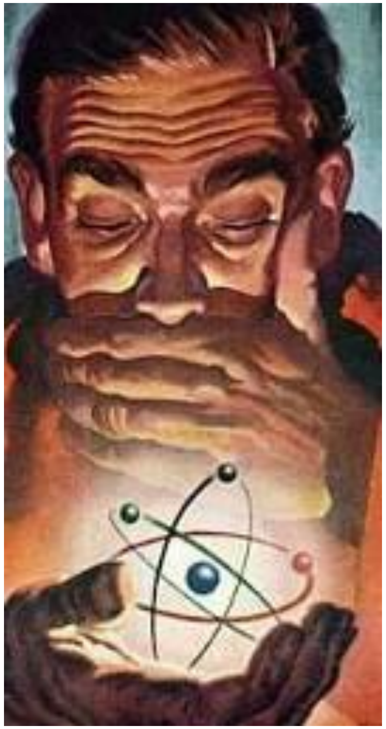
- ***Sustentabilidade:***
  - *oferecer geração de energia sustentável, capaz de atender objetivos de ar limpo e descarbonização da economia;*
  - *promover garantias em longo prazo do fornecimento de combustível nuclear e utilização efetiva de combustível para a produção de energia global*
  - *minimizar e gerenciar de forma segura os resíduos nucleares*
  - *e assim melhorar a proteção aos trabalhadores, ao público e ao meio ambiente.*

Futuro Tecnológico da Geração Elétrica Nuclear

- ***Economia***
  - *– **produzir uma clara vantagem em termos de custo de ciclo de vida em relação a outras fontes de energia***
  - *– **ter um grau de risco financeiro comparável a outros projetos de geração elétrica.***

Futuro Tecnológico da Geração Elétrica Nuclear

- ***Segurança e confiabilidade***
  - ***manter operações em alto nível de segurança e confiabilidade;***
  - ***manter a probabilidade e gravidade de danos no núcleo do reator ainda mais baixos;***
  - ***eliminar a necessidade de resposta a emergências externa ao sítio da usina;***
  - ***resistência à proliferação e proteção física***
    - ***inviabilizar o desvio ou roubo de materiais utilizáveis para a produção de armas;***
    - ***aumentar a proteção física contra atos de terrorismo.***



Sustentabilidade energética não pode prescindir da geração elétrica nuclear

MUITO OBRIGADO!