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Status and Future Potential of Small Modular Reactors (SMRs)

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The IAEA School of Nuclear Energy Management
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SMR DEFINITIONS

SMR can stand for both Small Modular Reactors, or also Small and Medium Size Reactors:

- **Small Size Reactors:** **10 – 300 MW [IAEA, DOE]**
- **Medium Size Reactors:** **300 – 700 MW [IAEA]**
- **Large Size Reactors:** **700 – 1700 MW [IAEA]**

A reactor can be Small or Medium Size and not Modular.

Modular means a multi-modular NPP on a common base mat, with NPP modules added when needed.

Overview - International

Current SMR Concepts

Near term SMR Project Status

List of SMR Concepts

Source: IAEA TECDOC 1451

SMR concept/design	Power level MW (thermal)	Products				Status		Layout			Special features
		Electricity, MW (electric)	Potable water, m^3/day	District heating, MW (thermal)	H_2 production m^3/day	Target commercialisation date	Licensing status	Integral	Maximum excess reactivity in hot full power state (HFP) ΔK/K	Modular	
Water cooled SMRs											
SMART (ROK)	330	90	40,000	-	-	2008 – Construct 1/5th prototype	Design and construction project of 1/5th prototype plant underway	Yes	BOC: 3.0%, EOC: 1.4%	Yes	Safeguard vessel. Lifetime core option was considered.
IRIS (International consortium led by Westinghouse, USA)	1000	343 (279 desalination option)	140,000	Yes, flexible	-	2012-2015 - First-of-a-kind plant	Pre-application licensing process started in October 2002	Yes	~11% (BOL, without Xe)	Yes	Lifetime core option was considered.
CAREM (Argentina)	900	300	48,000 plus 125 MW(e) (CAREM-125)	-	-	27 MW(e) prototype in 2006 2011 – Commercial plant	Detailed design stage, licensing pre-application made	Yes	3.6% (CAREM-25 prototype core with 3.1% enrichment)	Yes	Lifetime core option was considered.
SCOR (France)	2000	630	-	-	-	2010	Conceptual design	Yes	n/a	-	Increased fuel burn-up.

List of SMR Concepts (2)

Source: IAEA TECDOC 1451

SMR concept/design	Power level MW (thermal)	Products				Status		Layout			Special features
		Electricity, MW (electric)	Potable water, m^3/day	District heating, MW (thermal)	H_2 production m^3/day	Target commercialisation date	Licensing status	Integral	Maximum excess reactivity in hot full power state (HFP) $\Delta K/K$	Modular	
SAKHA-92 (Russia)	7.0	1.0	-	1.2-3.0	-	2008	Preliminary design, licensing pre-application made	Yes	n/a	-	Lifetime core (25 years). Floating NPP option was considered.
ABV-3 (Russian Federation)	16	2.5	-	5.8	-	2008	Detailed design, licensing pre-application made	Yes	n/a	Yes	Floating and land based NPP options.
ABV-6 (Russian Federation)	38	6	-	14	-	2008	Detailed design, Licensing pre-application made	Yes	n/a	Yes	Floating and land based NPP options. Lifetime core (10-12 years).
KLT-40S (Russian Federation)	2×150	60	40,000 – 100,000	40.5	-	2007	Detailed design finalized; license for construction in Severodvinsk (Russia) obtained	-	n/a	-	Floating NPP option. Lifetime core option under consideration (10-12 years).

List of SMR Concepts (3)

Source: IAEA TECDOC 1451

SMR concept/design	Power level MW (thermal)	Products				Status		Layout			Special features
		Electricity, MW (electric)	Potable water, m^3/day	District heating, MW (thermal)	H_2 production m^3/day	Target commercialisation date	Licensing status	Integral	Maximum excess reactivity in hot full power state (HFP) ΔK/K	Modular	
VBER-150 (Russian Federation)	350	110	Yes	Yes	-	2008	Preliminary design; no licensing pre-application	-	n/a	Yes	Floating and land based NPP options. Lifetime core (7-8 years).
RIT (Russian Federation)	161	42	80,000	Up to 110	-	2008	Preliminary design	Yes	-	-	Floating or land based nuclear desalination complex.
RUTA-70 (Russian Federation)	70	-	-	70	-	n/a	Conceptual design	-	n/a	-	Could be constructed close to the consumers.
UNITHERM (Russia)	15	1.5	-	4.65	-	n/a	Conceptual design	Yes	n/a	Yes	Lifetime core (20 years).
NIKA-70 (Russian Federation)	70	15	Yes	-	-	n/a	Conceptual design	Yes	n/a	-	A floating NPP.
ELENA (Russian Federation)	3.3	0.068	-	Up to 3	-	2010-2015	Conceptual design	Yes	Near-zero – "Self-regulating reactor"	-	Unattended operation. Lifetime core (25 years).

List of SMR Concepts (4)

Source: IAEA TECDOC 1451

SMR concept/design	Power level MW (thermal)	Products				Status		Layout			Special features
		Electricity, MW (electric)	Potable water, m^3/day	District heating, MW (thermal)	H_2 production m^3/day	Target commercialisation date	Licensing status	Integral	Maximum excess reactivity in hot full power state (HFP) $\Delta K/K$	Modular	
AHWR (India)	920	300	500	-	-	2012	Basic design completed; detailed design in progress; licensing pre-application made; initiation of construction actions targeted for late 2004	-	~1%	-	Land based NPP.
PFPWR50 (Japan)	50	-	-	50	-	2012-2015	Conceptual design of the core	n/a	3% (without Xe) ~0.3% (with equilibrium Xe)	n/a	Lifetime core (10 years).
VKR-MT (Russian Federation)	890	300	-	Up to 600	-	2015-2020	Conceptual design	No	6%	No	Lifetime core (10 years).

List of SMR Concepts (5)

Source: IAEA TECDOC 1451

SMR concept/design	Power level MW (thermal)	Products				Status		Layout			Special features
		Electricity, MW (electric)	Potable water, m^3/day	District heating, MW (thermal)	H_2 production m^3/day	Target commercialisation date	Licensing status	Integral	Maximum excess reactivity in hot full power state (HFP) $\Delta K/K$	Modular	
FBNR (Brazil)	30 per module	10	Yes	Yes	-	2012-2015	Conceptual design	Yes	Near zero. Reactivity margin is 'stored' in the fuel located outside the core.	Yes	Long-life core. Factory fabricated and fuelled reactor.
Gas cooled SMRs											
PBMR-400 (South Africa)	400	278	Yes	-	Yes	2010	Preliminary design	-	1.3%	X	Direct cycle gas turbine.
HTR-PM (China)	380	160	-	-	-	2010	Conceptual design	-	~1%	Yes	Indirect cycle with reheating; steam turbine
HTR (AREVA)	n/a	n/a	n/a	-	Yes	2015	Conceptual design	-	n/a	Yes	

List of SMR Concepts (6)

Source: IAEA TECDOC 1451

SMR concept/design	Power level MW (thermal)	Products				Status		Layout			Special features
		Electricity, MW (electric)	Potable water, m^3/day	District heating, MW (thermal)	H_2 production m^3/day	Target commercialisation date	Licensing status	Integral	Maximum excess reactivity in hot full power state (HFP) ΔK/K	Modular	
VHTR (Generation-IV)	600	n/a, optional	-	-	Yes	2030	Feasibility study	-	n/a	n/a	Advanced process heat applications.
Liquid metal cooled SMRs											
SVBR-75/100 (Russia)	280	101.5	Yes	Yes	-	2012	Detailed design stage; licensing pre-application not made yet	Yes	3.8% with UO_2 0.17% with UN	Yes	Lifetime core (6-8 years). Advanced process heat applications. Floating and land based NPP options.
SSTAR (USA)	25-50	10-25	Yes	-	-	2015	Feasibility Study	Yes	n/a	Yes	Lifetime core (target: 15-20 years)
STAR-LM (USA, Generation-IV)	400	178	Yes	-	-	2020	Conceptual design stage	Yes	~5.0%	Yes	Lifetime core (20 years). Passive load follow operation.

List of SMR Concepts (7)

Source: IAEA TECDOC 1451

SMR concept/design	Power level MW (thermal)	Products				Status		Layout			Special features
		Electricity, MW (electric)	Potable water, m^3/day	District heating, MW (thermal)	H_2 production m^3/day	Target commercialisation date	Licensing status	Integral	Maximum excess reactivity in hot full power state (HFP) $\Delta K/K$	Modular	
STAR-H2 (USA, Generation-IV)	400	-	8000	-	170 MW (thermal) - lower heating value	2030	Conceptual design stage	Yes	n/a	Yes	Lifetime core (20 years). Passive load follow operation.
SPINNOR	27.5/55	10/20	Yes	-	-	2020	Conceptual design stage	Yes	~0.35%	Yes	Lifetime core (25/15 years).
VSPINNOR	17.5	6.25	Yes	-	-	2020	Conceptual design stage	Yes	~0.35%	Yes	Lifetime core (35 years)
Non-Conventional SMRs											
MARS (Russian Federation)	16	Up to 6 MW	Yes	Up to 8.5	Various process heat applications	2025-2030	Conceptual design stage	Yes	3%	n/a	Lifetime core (15 or 60 years). Floating, land based or underground NPP options considered. Autonomous source of power and heat.

List of SMR Concepts (8)

Source: IAEA TECDOC 1451

SMR concept/design	Power level MW (thermal)	Products				Status		Layout			Special features
		Electricity, MW (electric)	Potable water, m^3/day	District heating, MW (thermal)	H_2 production m^3/day	Target commercialisation date	Licensing status	Integral	Maximum excess reactivity in hot full power state (HFP) ΔK/K	Modular	
CHTR (India)	0.1	n/a, Brayton cycle plus thermoelectric conversion	Yes	-	Thermo-chemical processes plus electrolysis	2015	Conceptual design stage	Yes	~11%	n/a	Lifetime core (5 years). Compact power pack for remote places and for hydrogen production
CANDLE (Japan)	A fuel burn-up / fuel cycle concept for thermal and fast reactors; provides for a high degree of natural uranium utilization without the recycle and reprocessing of spent nuclear fuel. The deployment projection for CANDLE - HTGR is 2015; the deployment projection for CANDLE - fast reactors is 2040-2045. The degree of natural uranium utilization in CANDLE – fast reactors may reach 40% (absolute).										

NOTE: CANDLE is an old concept. In U.S. it is called Traveling Wave Reactor (TeraPower / Bill Gates).

List of SMR Concepts (9)

Source: WNA - Small Nuclear Power Reactors, September 2010

Medium and Small (25 MWe up) reactors with development well advanced

Name	Capacity	Type	Developer
KLT-40S	35 MWe	PWR	OKBM, Russia
VK-300	300 MWe	PWR	Atomenergoproekt, Russia
CAREM	27 MWe	PWR	CNEA & INVAP, Argentina
IRIS	100-335 MWe	PWR	Westinghouse-led, international
mPower	125 MWe	PWR	Babcock & Wilcox, USA
SMART	100 MWe	PWR	KAERI, South Korea
NuScale	45 MWe	PWR	NuScale Power, USA
HTR-PM	2x105 MWe	HTR	INET & Huaneng, China
PBMR	80 MWe	HTR	Eskom, South Africa
GT-MHR	285 MWe	HTR	General Atomics (USA), Rosatom (Russia)
BREST	300 MWe	LMR	RDIPE, Russia
SVBR-100	100 MWe	LMR	Rosatom/En+, Russia
FUJI	100 MWe	MSR	ITHMSO, Japan-Russia-USA

IAEA concluded 2009 there could be 96 / 43 (hi/low) SMRs in operation by 2030 – and the following types

Name	Capacity	Type	Developer
KLT-40S	35 MWe	PWR	OKBM, Russia
VK-300	300 MWe	PWR	Atomenergoproekt, Russia
CAREM	27 MWe	PWR	CNEA & INVAP, Argentina
IRIS	100-335 MWe	PWR	Westinghouse
mPower	125 MWe	PWR	Babcock & Wilcox, USA
SMART	100 MWe	PWR	KAERI, South Korea
NuScale	45 MWe	PWR	NuScale Power, USA
HTR-PM	2x105 MWe	HTR	INET & Huaneng, China
PBMR	80 MWe	HTR	Eskom, South Africa
GT-MHR	285 MWe	HTR	General Atomics (USA), Rosatom (Russia)
BREST	300 MWe	LMR	RDIPE, Russia
SVBR-100	100 MWe	LMR	Rosatom/En+, Russia
FUJI	100 MWe	MSR	ITHMSO, Japan-Russia-USA

SMRs under Construction

Source: WNA – Country Briefing

Russia:

Vilyuchinsk Floating NPP (KLT-40S, 2x40 MW) – Ship *“Academician Lomonosov”*
21,500 tonne hull, 144 m long and 30 m wide
Construction start 05/2009, Commercial Operation 2012
2 x PWR (<20% U235) based on Icebreaker reactor design

SMRs under Construction (2)

Source: WNA – Country Briefing

SMRs under Construction (3)

Source: WNA – Country Briefing

Argentina:

Prototype CAREM *(Central Argentina Modular Elements Reactor)*
(simplified modular natural circulation PWR, integral Steam Generators, using standard 3.4% U235 PWR fuel, 27 MWe. Can be scaled to 150 MWe)
Construction start 2010, Commercial Operation – n/a

SMRs under Construction (4)

Source: WNA – Country Briefing

SMRs under Construction (5)

Source: WNA – Country Briefing

China:

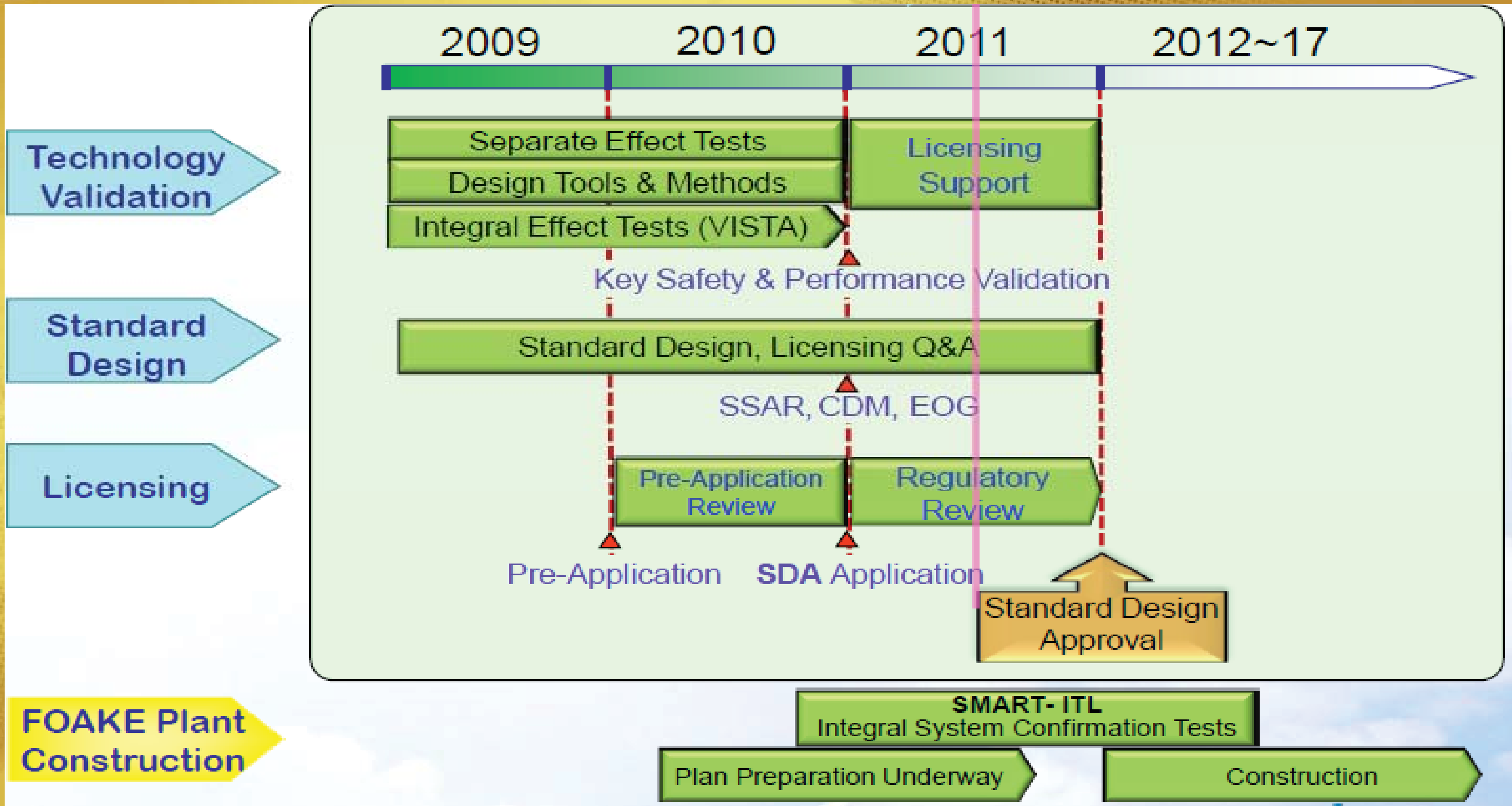
Shidaowan - Demonstration HTR-PM, using Pebble-Bed concept
2x105 MWe reactor units driving a single 210 MWe Turbine
EPC contract placed 10/2008, site work completed
Construction start – planned end of 2010. Startup planned 2015

South Korea:

Prototype SMART (System-integrated Modular Advanced Reactor)
65 MWth Prototype design completed
Commercial SMART-100 has 330 MWth
SMART-100 FOAK SMR startup expected earliest by 2017+
Overnight construction cost target ~$5,800/kWe (equal to Generation-III/III+ NPPs)

SMART-100 Time Schedule

Source: KAERI Presentation – July 2011



Overview – U.S.

Current Status and Activities for Small Modular Reactors (10 – 300 MW)

Fast Growing Interest in U.S. in SMRs

There are several trends in Nuclear New Build (NNB) market favoring smaller modularized NPP types:

- NNB itself has become accepted by public opinion (climate change)
- New large NPPs have become expensive (about $6-$9B per reactor)
- Financing new NPPs has become difficult and LGs are needed (Utility Market Cap is too small compared to NNB investment at risk)
- Large reactor size (1,700 MW) adds more capacity / increment than often needed at a time (additional financial risk)
- Financial risks of cost/schedule overrun on large NNB projects
- SMRs can offer a "way out" for utilities to avoid above challenges

Fast Growing Interest in U.S. in SMRs (2)

- U.S. Nuclear renaissance has practically stalled, because of "discovery" of large deposits of "shale gas", and waiting for Loan guarantees

- U.S. Utility interest is growing rapidly in "small / modular" reactors that cost ~5 to 10x less, and can be put in operation in ~¼ to ½ of the time needed for a large reactor

- A utility could expand their production capacity in smaller more manageable increments, while receiving cash flow from reactor modules coming on-line

- <u>Replication</u> (factory 'assembly line') could bring costs down dramatically, <u>while raising NPP quality significantly</u>

Fast Growing Interest in U.S. in SMRs (3)

Source: TVA Presentation Nov 2010

- Re-powering aging fossil sites (reusing assets such as environmental permits, transmission and water availability)
- SMR size fits easy with grid reliability requirements
- Re-establishing U.S. manufacturing base for nuclear components
- Will the SMRs replace the large NPPs (like PC replaced Mainframes)?
- Maybe not, because of the NUCLEAR price tag

Fast Growing Interest in U.S. in SMRs (4)

Source: TVA Presentation Nov 2010

Construction Period Finance Drivers

	Large Unit (1100-1200 MW)	SMR (250 -280 MW)
Total escalated cost per unit	$5-7 Billion	$1.4 - 1.8 Billion
Construction duration First concrete to fuel load	46 mo.	30 mo.
Site preparation work	18-24 mo.	12-18 Mo.
Percent of EPC Contract Price Fixed	40-60%	60-80%

Less strain on balance sheet

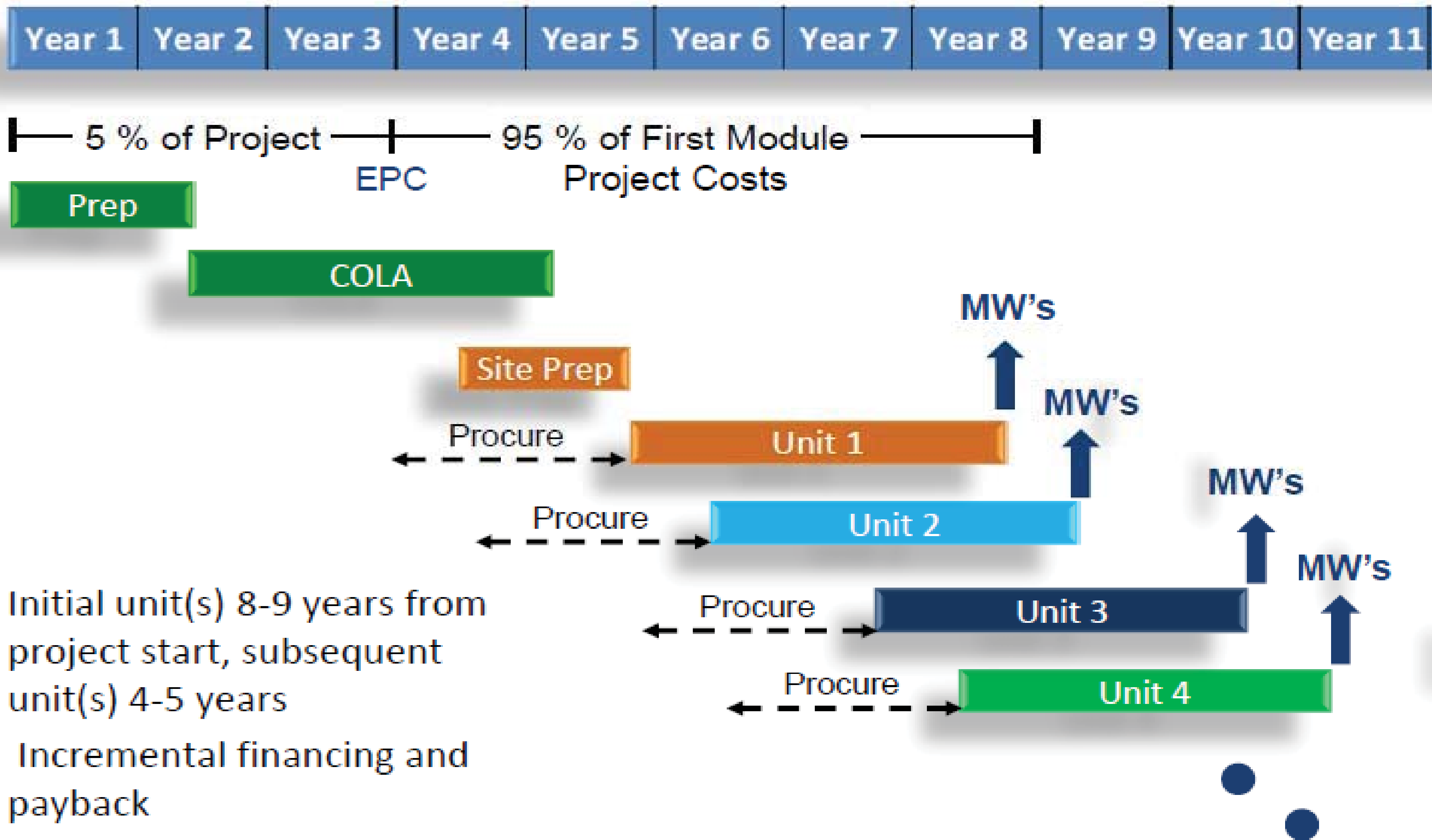
Quicker completion Less interest cost

Less risk

Lower cost of capital

Fast Growing Interest in U.S. in SMRs (5)

Source: TVA Presentation Nov 2010



Initial unit(s) 8-9 years from project start, subsequent unit(s) 4-5 years

Incremental financing and payback

Overview – U.S.

NRC Activities in Support of Small Modular Reactors (10 – 300 MW)

NRC is looking at these SMRs

- Light Water Reactor – '*familiar technology*'

– IRIS	335 MW	Westinghouse
– mPower	125 MW	B&W
– NuScale	45 MW	NuScale Power

- Sodium Fast Reactor – '*less familiar technology*'

– PRISM	311 MW	GE-Hitachi
– 4S	10 MW	Toshiba

- Lead-Bismuth coolant – '*exotic technology*'

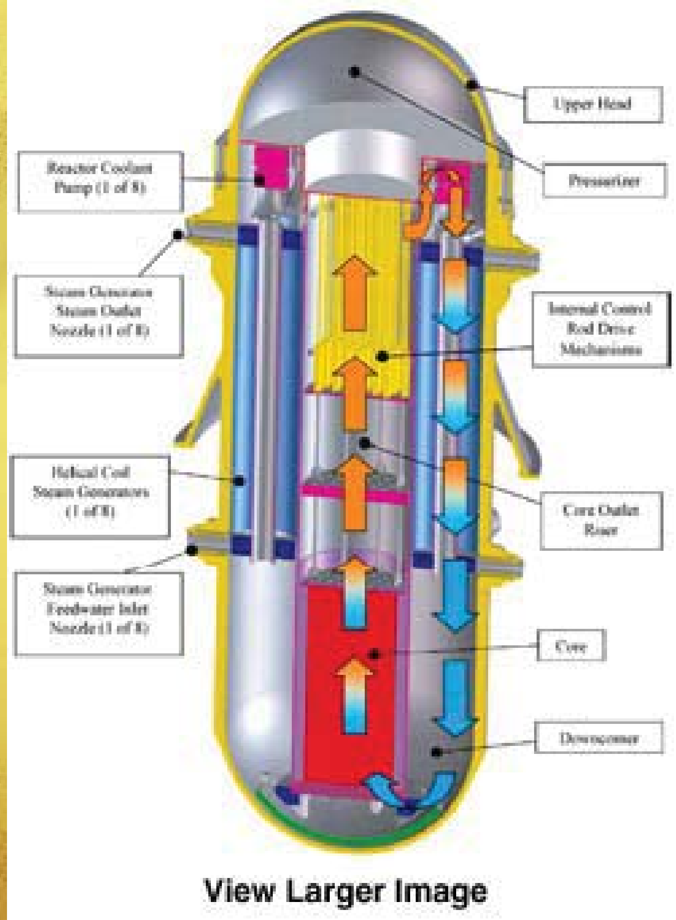
– Hyperion	25 MW	Hyperion Power Generation

- Gas cooled reactor – '*prototype technology*'

– PBMR	165 MW	PBMR Ltd

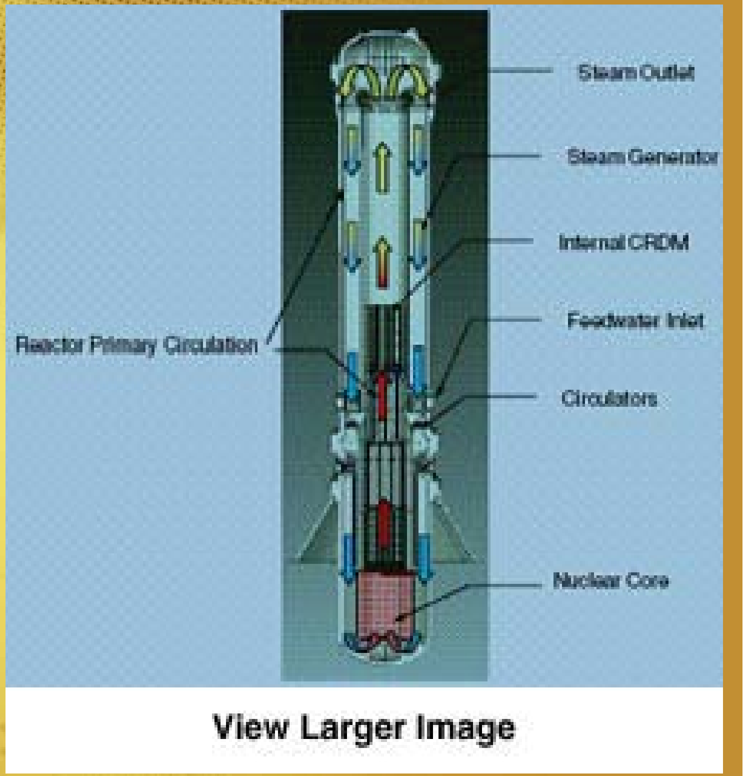
Westinghouse - IRIS

Designer:	Westinghouse Electric Company
Reactor Power:	1000 MWt
Electrical Output:	335 MWe
Outlet Conditions:	330° C
Coolant:	Light Water
Fuel Design:	17 x 17 assemblies 4.95% enrichment UO_2
Refueling:	3-3.5 years
Letter of Intent:	Updated March 18, 2009
Licensing Plan:	Design Certification
Expected Submittal:	Q3 2012
Design Information:	Pressurized water reactor with reactor vessel, helical-coil steam generators, reactor coolant pumps, and pressurizer within a reactor vessel which is enclosed in a spherical steel containment vessel.



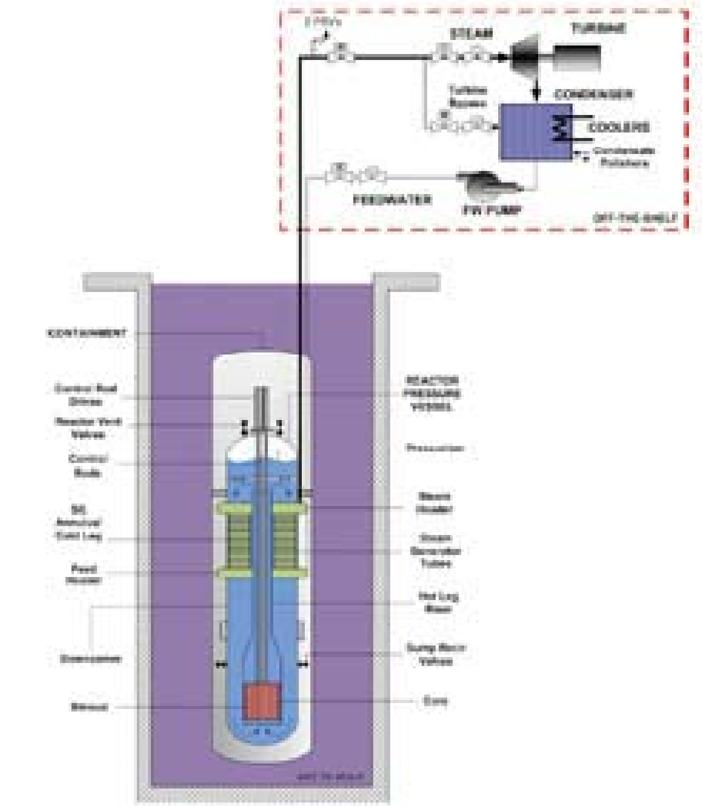
B&W - mPower

Designer:	Babcock & Wilcox Company (B&W)
Reactor Power:	400 MWt
Electrical Output:	125 MWe
Outlet Conditions:	327° C
Coolant:	Light water
Fuel Design:	*Proprietary*
Refueling:	*Proprietary*
Letter of Intent:	April 28, 2009
Licensing Plan:	Design Certification
Expected Submittal:	Q4 CY 2012
Design Information:	LWR with the reactor and steam generator located in a single reactor vessel located in an underground containment.
Status/Other Info:	Pre-Application stage for Design Control Document (DCD)
Website:	http://www.babcock.com/products/modular_nuclear/



NuScale

Designer:	NuScale Power, Inc.
Reactor Power:	150 MWt
Electrical Output:	45 MWe
Outlet Conditions:	1500 psig, 575° F
Coolant:	Light Water
Fuel Design:	17 x 17 fuel bundles, 6', 4.95% enrichment
Refueling:	24 months
Letter of Intent:	January, 2008
Licensing Plan:	Design Certification
Expected Submittal:	Q2 FY 2012
Design Information:	Natural circulation light water reactor with the reactor core and helical coil steam generators located in a common reactor vessel. The reactor vessel is submerged in a pool of water.
Status/Other Info:	Pre-Application stage for Design Control Document (DCD). Based on MASLWR (Multi-Application Small Light Water Reactor) developed at Oregon State University in the early 2000s.
Website:	http://www.nuscalepower.com/



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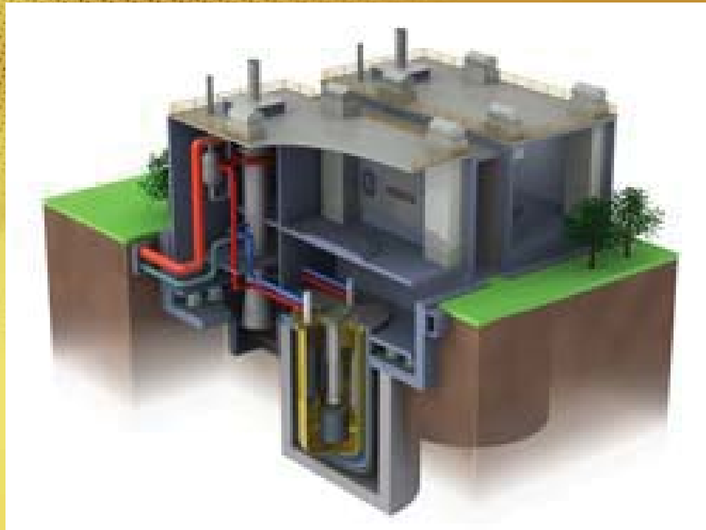
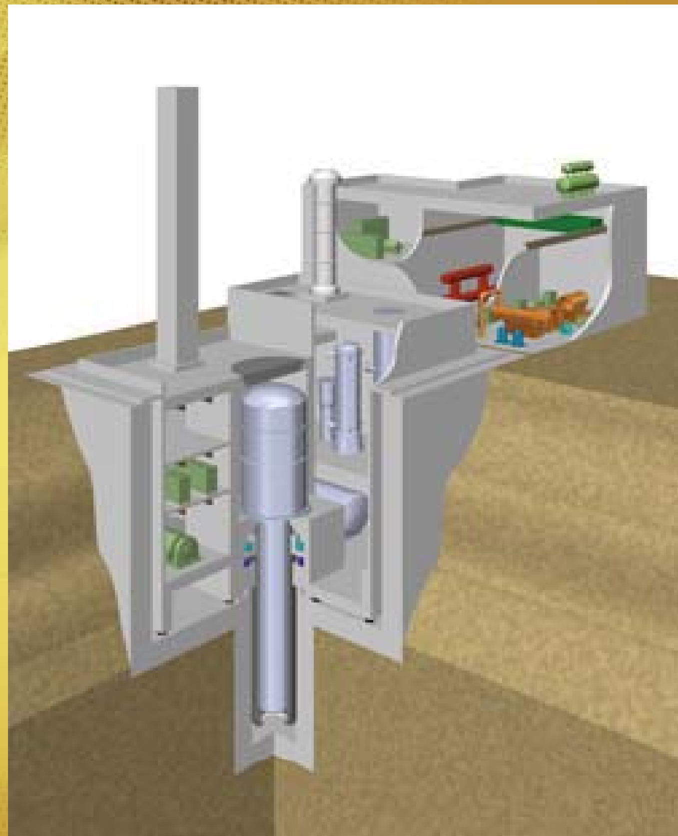
GE-Hitachi - PRISM



Designer:	GE Hitachi Nuclear Energy (GE-H)
Reactor Power:	840 MWt
Electrical Output:	311 MWe
Outlet Conditions:	930° F
Coolant:	Liquid metal (sodium)
Fuel Design:	Metallic
Refueling:	12-24 months
Letter of Intent:	Updated March 15, 2010
Licensing Plan:	COL Prototype (long-term - Manufacturing License)
Expected Submittal:	First quarter 2012
Design Information:	Underground containment on seismic isolators with a passive air cooling ultimate heat sink. Modular design with two reactor modules per power unit (turbine generator).
Status/Other Info:	NRC staff conducted pre-application review in early 1990s that resulted in the publication of NUREG-1368, "Preapplication Safety Evaluation Report for the Power Reactor Innovative Small Module (PRISM) Liquid-Metal Reactor (January 1994)."

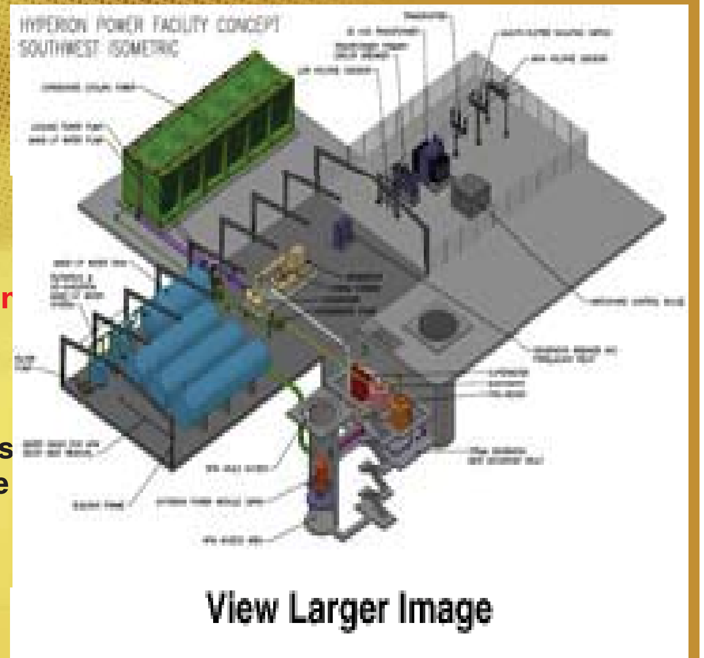
Toshiba – 4S

Designer:	Toshiba Corporation
Reactor Power:	30 MWt
Electrical Output:	10 MWe
Outlet Conditions:	510° C
Coolant:	Liquid-metal (sodium)
Fuel Design:	18 hexagonal fuel assemblies - U-10%Zr Alloy with 19.9% enrichment
Refueling:	30 years
Letter of Intent:	Updated March 23, 2010
Licensing Plan:	Design Approval
Expected Submittal:	Second quarter 2012
Design Information:	Small, sodium-cooled, underground reactor
Status/Other Info:	Working with the city of Galena, AK as a potential COL partner.



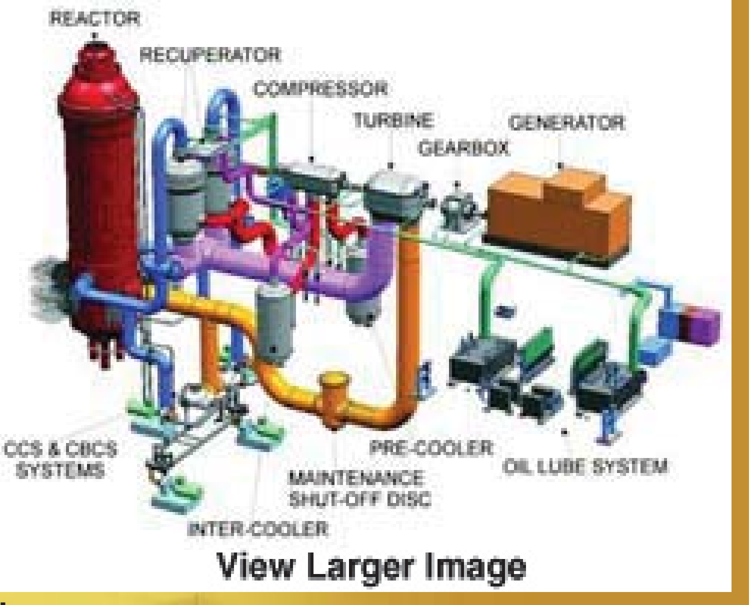
Hyperion – HPM module

Designer:	Hyperion Power Generation, Inc.
Reactor Power:	70 MWt
Output:	25 MWe
Outlet Temp	500C
Coolant:	Lead-bismuth eutectic, primary secondary loops
Fuel Design:	Stainless steel clad uranium nitride
Refueling:	Entire reactor module replaced every 7 to 10 years
Licensing Plan:	Combined License (prototypical design) and/or Design Certification
Design Information:	The HPM is sealed at the factory, sited underground, and eventually returned to the factory for waste and fuel disposition after a useful life of seven to ten years The principle materials in the core are uranium nitride (UN) fuel, stainless steel as the structural material, lead-bismuth eutectic (LBE) as the coolant, quartz as the radial reflector, B4C rods and pellets for in-core reactivity control and shutdown. The LBE permits ambient pressure operation of core, eliminating pressure vessel requirements.
Status/Other Info:	The outer diameter of the entire reactor system, including the outer reflector and coolant downcomer, is limited to 1.5 m to be able to seal the reactor vessel system at the fabrication facility and transport it to the site in a conventional nuclear fuel shipping cask. The total mass of the reactor vessel with fuel and coolant is <20 metric tons.
Website:	http://www.hyperionpowergeneration.com/



PBMR Ltd – PBMR module

Designer:	PBMR (Pty.), Ltd.
Reactor Power:	400 MWt
Electrical Output:	165 MWe
Outlet Conditions:	Up to 900° C (1652° F)
Coolant:	Helium
Fuel Design:	~450,000 low-enriched UO_2 TRISO fuel particles in pebbles
Refueling:	Online
Letter of Intent:	Updated March 24, 2009
Licensing Plan:	Design Certification
Expected Submittal:	FY2013
Design Information:	Modular, gas-cooled, pebble bed reactor with online refueling that generates electricity via a gas or steam turbine and which may also be used for process heat applications.
Status/Other Info:	Licensing of a demonstration plant in South Africa is being reconsidered. Agreement with Chinese for cooperation in development.
Website:	http://www.pbmr.co.za/



NRC is <u>not</u> yet looking at

- Light Water Reactor – '*familiar technology*'
  - AP200 (225 MW) Westinghouse (integral PWR using AP1000 safety technology) replaces IRIS?
- Sodium Fast Reactor – '*less familiar technology*'
  - ARC-100 (125 MW) Based on EBR-II experience
    20 years fuel cycle, metal fuel
- Gas cooled reactor – '*prototype technology*'
  - EM2 (240 MW) General Atomic He-cooled Fast Reactor
    12 years, $1.7 B needed for development
    30 yrs fuel cycle, runs on LWR spent fuel

Overview – U.S.

DOE and Political Support for Small Modular Reactors (10 – 300 MW)

DOE & Political Support of U.S. SMRs

DOE Chief Steven Chu calls SMRs ”America’s new Nuclear Option”, and suggests two choices “America develops SMR technologies today or imports them tomorrow.

- **2011 DOE Budget request contains $39M for SMRs**
- **Nuclear Power 2021 Act - seeks to authorize DOE to lead a PPP (Public-Private-Partnership) to develop innovative SMRs**
- **The Nuclear Energy Research Initiative Improvement Act – aims at providing DOE with $2.5B in next 5 years for SMR commercialization**
- **The SMRs have caught the imagination of U.S. Policy Makers**
- **SMRs are likely to be more publically acceptable than large ALWRs**

DOE Support of SMR Validation

- Savannah River (DOE Site):
  - **Hyperion** to build a demo plant of their 25MW design (Fast Reactor using Uranium Nitride fuel and Lead-Bismuth Eutectic Coolant)
  - Prototype in operation by 2017/18 (costing ~$50M)
  - **DOE/Savannah Rive is discussing with 5-6 other SMR vendors to build prototypes**
  - **All Demo SMRs at DOE's Savannah Site will use either Plutonium, or high-enriched Uranium, or Spent Fuel, <u>and Light Water Reactor types will be excluded (i.e., known technology)</u>**

SMR Technology Introduction
Expected Time Table (DOE)

Source: NRC Workshop on SMRs, October 2009

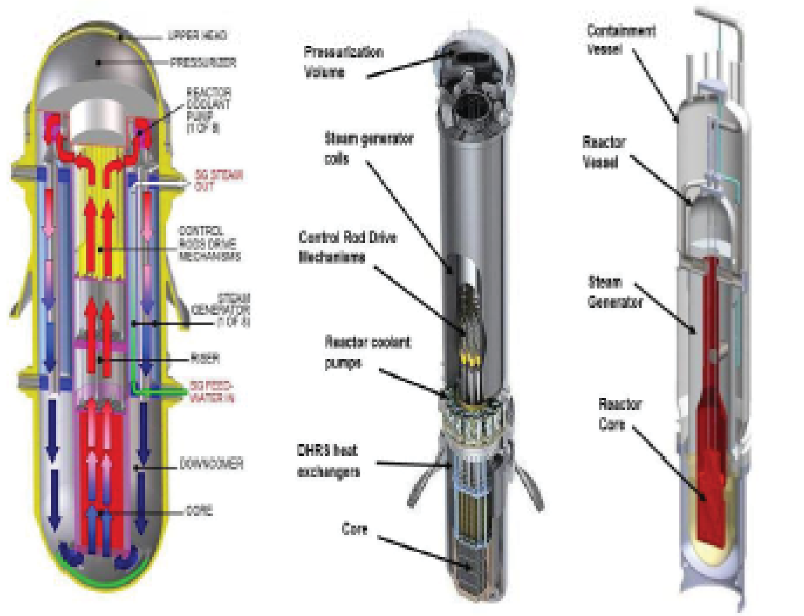
SMR designs and concepts can be grouped into three sets based on design type, licensing and deployment schedule, and maturity of design:

- **LWR based designs**
  - **» 5-10 years**
- **Non-LWR designs**
  - **» 10-15 years**
- **Advanced Reactor Concepts and Technologies**
  - **» 15-25 years**

Expected Near-Term SMRs in U.S.

Source: DOE Presentation to Nuclear Infrastructure Council, Dec 2010

- Well-Understood Technology
  - LWR based designs
  - Standard <5% UO2 fuel
  - Regulatory and operating experience
- Commercial Interest
  - At least 2-3 credible LWR vendors
  - Vendor/Utility coalitions forming
- Manufacturing industry mobilizing
  - Revitalize US nuclear infrastructure & Navy shipbuilding industry
- Potential for operation by 2020, NRC licensed
- DOE and DoD as customers for SMR electricity

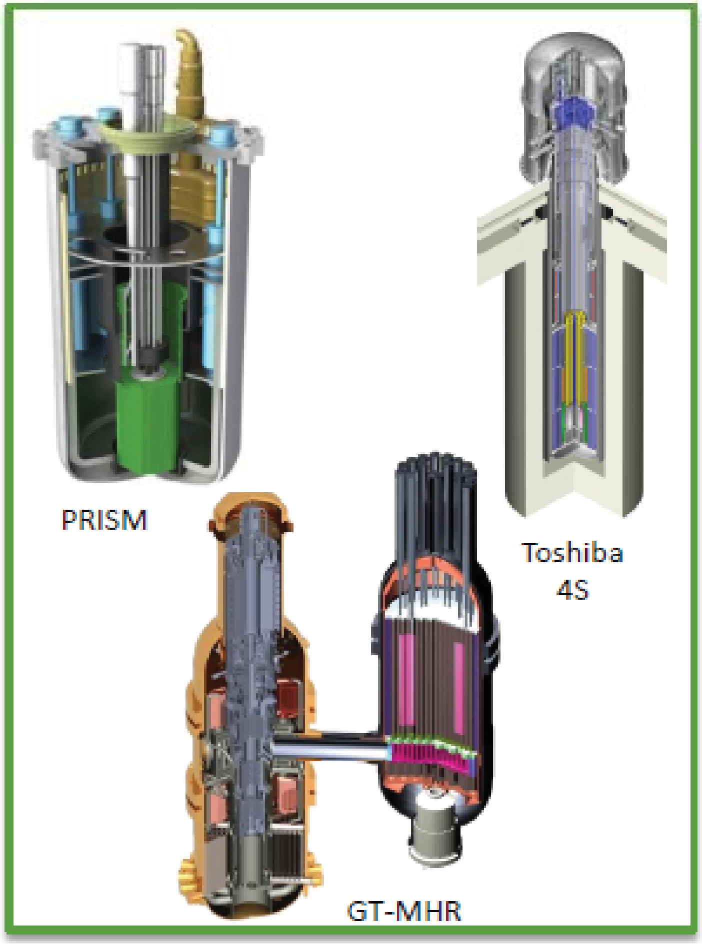


IRIS (Westinghouse) 335 MWe | *mPower (Babcock & Wilcox)* 125 MWe | *NuScale (NuScale)* 45 MWe

Expected Longer-Term SMRs in U.S.

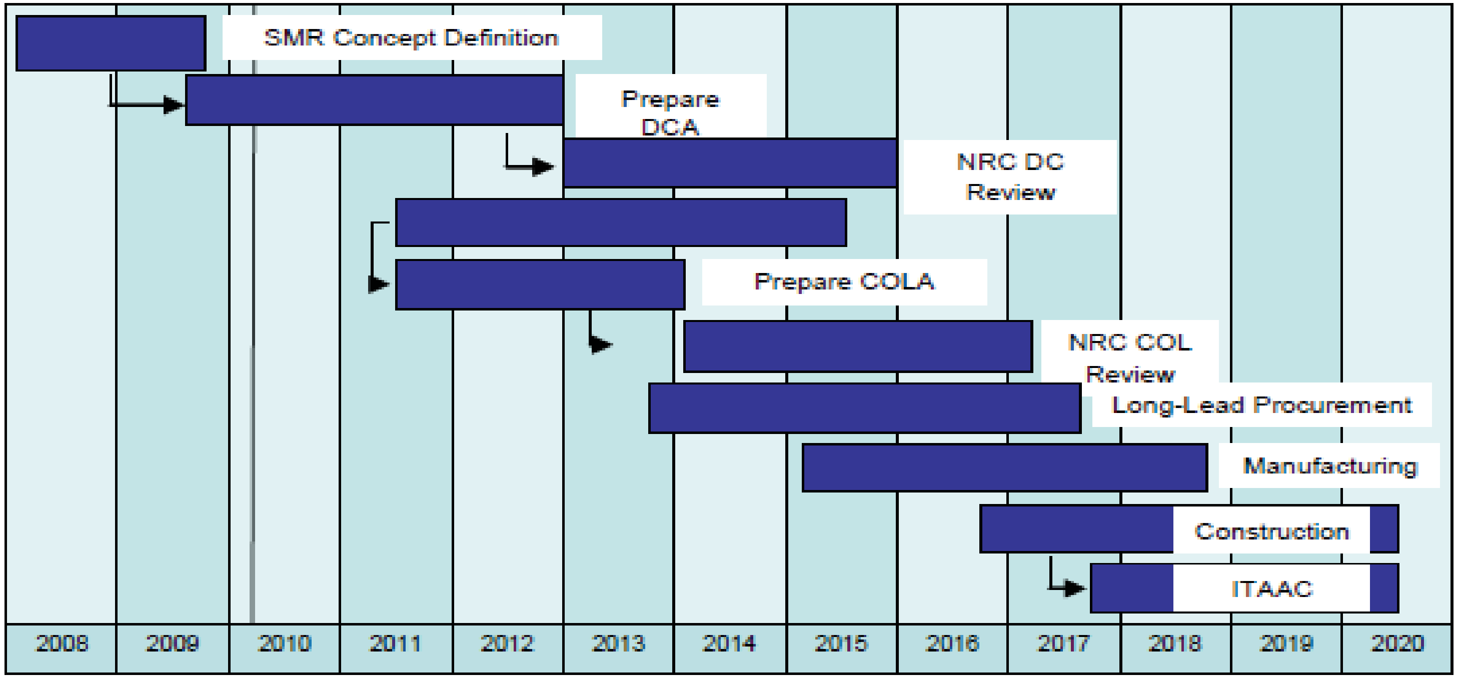
Source: DOE Presentation to Nuclear Infrastructure Council, Dec 2010

- New innovative technologies
  - Mostly non-LWR based designs
  - Goal: Extended applications for nuclear energy
  - Characteristics: Safer, simpler, extended fuel life, proliferation resistant, higher temperature
- Broader applications
  - Distributed power production
  - Process heat applications
    - Oil refining and extraction
    - Desalination
    - Chemical and hydrogen production
    - Biofuel & Synfuel production
- Nuclear Fuel Management
  - Respond to Blue Ribbon Commission recommendations
  - Support advanced fuel cycles



Nominal SMR Licensing Schedule

Source: DOE Presentation to Nuclear Infrastructure Council, Dec 2010



- NRC responding to SMR interest
  - SECY 10-0034 identified issues with SMR licensing
  - Office of New Reactors includes SMR certification & licensing
  - FY2011 budget request calls for doubling NRC staff to support SMR review and licensing
  - NRC and industry (NEI) currently working on SMR licensing/regulatory issues

Overview – U.S.

Major Challenges

for Small Modular Reactors

(10 – 300 MW)

MAJOR CHALLENGES FOR SMRs

- **Regulatory Resources & Licensing Requirements**
  - <u>too many SMR designs for NRC to review and approve</u>
  - SMR Design Certification and Licensing effort <u>equal</u> to large commercial NPPs (or more for non-familiar technology concepts)
  - supervision of large number of sites/installations
- **Nuclear Rules and Regulations**
  - internationally accepted SMR regulations (e.g., like FAA-style)
  - impractical to have individual SMR regulations in each country
- **Nuclear Safeguards & Logistics challenges**
  - monitoring (thousands?) of SMR sites in 3rd world countries

MAJOR CHALLENGES FOR SMRs (2)

- **Nuclear Non-proliferation**
  - **many new challenges with (large) number of SMRs worldwide**
  - **Especially if they are ‘transportable’**
- **Nuclear Waste**
  - **Logistics with large number of new sites**
  - **Transports from large number of new sites**
- **Public Acceptance**
  - **Public opinion now ‘accepts’ a <u>few</u> large NPP sites in a country**
  - **What about <u>large</u> number of SMR sites in a country (‘NIMBY’)?**
- **Nuclear Liability**
  - **Nuclear Liability Insurance (worldwide, w/o Price-Anderson)**

MAJOR CHALLENGES FOR SMRs (3)

- NRC Resources to handle <u>too many</u> different SMR designs
- Licensing schedule (~42 months for advanced LWRs)
- SMR Prototype testing requirements
- New NUREGs for SMRs
- Emergency Planning
- Staffing / manpower
- Security & Non-proliferation (thousands of SMR sites)
- Nuclear Waste (<u>non-standard fuel, many types</u>)
- Multi-module construction issues (e.g., aircraft protection)
- Insurance (Price Anderson)
- Financial Qualifications rules
- NRC Fee rule

Overview – U.S. DOE Program

Next Generation Nuclear Plant (NGNP)

(200 - 600 MWth / 80 - 250 MWe)

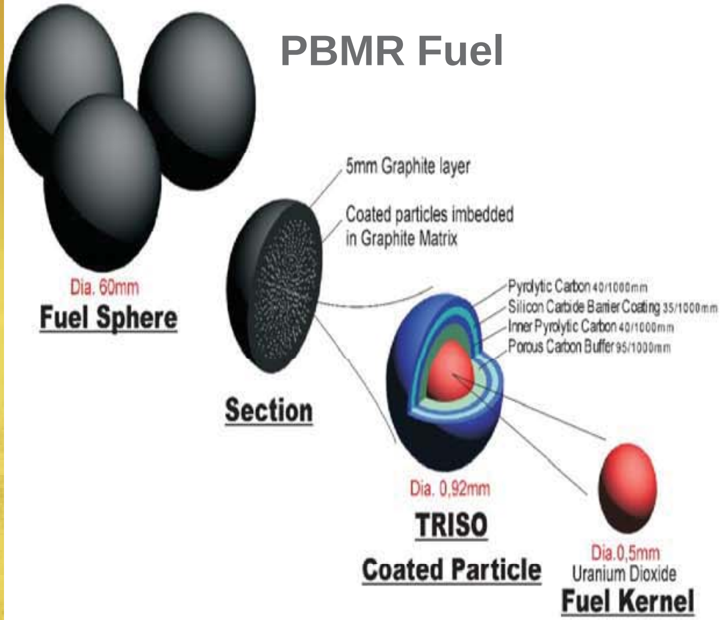
Small Modular High Temperature Reactors

Next Generation Nuclear Plant

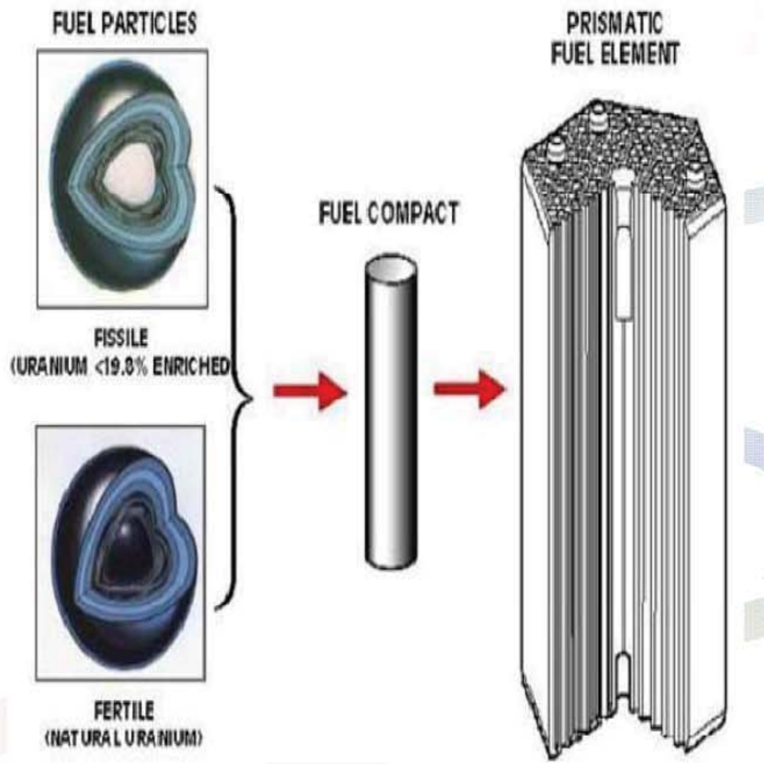
Sponsor:	Department of Energy (DOE)
Designer:	To be determined (TBD)
Reactor Power:	TBD
Electrical Output:	TBD
Outlet Conditions:	>750 C
Coolant:	Gas-cooled
Fuel Design:	Prismatic or Pebble Bed
Refueling:	TBD
Letter of Intent:	See NGNP Licensing Strategy Report to Congress (August 2008)
Licensing Plan:	Combined License
Expected Submittal:	FY 2013
Design Information:	DOE is currently selecting which reactor design will be used for the NGNP. NGNP is part of the Generation IV program.
Status/Other Info:	Required by Energy Policy Act of 2005. The staff has been working with DOE on the licensing strategy for the plant and provided the NGNP Licensing Strategy Report to Congress in August 2008.
Website:	http://www.ne.doe.gov/neri/neneriresearch.html

Next Generation Nuclear Plant (2)

PBMR Fuel



Prismatic Fuel – e.g., AREVA ANTARES, GA HTGR



U.S. NGNP – Time Schedule

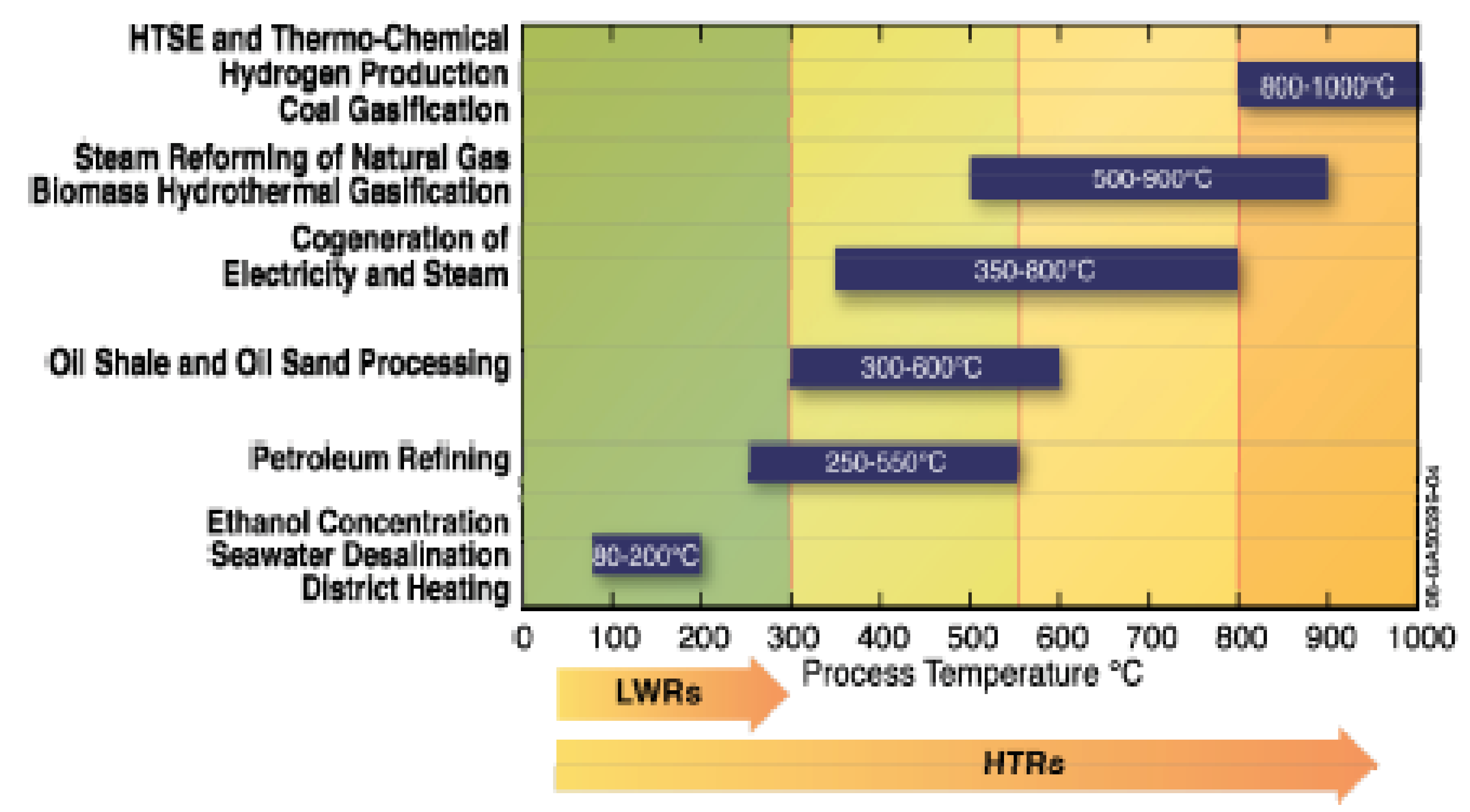
Source: 2008 NGNP Report to Congress

DOE/NRC estimate of the schedule to develop, review, construct an NGNP under recommended licensing strategy (Subpart C of 10CFR Part 52):

- 2008–2011 Programmatic and key technical issues identified, design underway
- 2011–2013 Design and COL application developed
- 2013 COL application submitted
- 2016 Applicant begins site preparation activities
- **2017 COL issued and safety-related construction begins at INL/Idaho**
- **2021 Construction complete and fuel loading begins**
- **Total licensing cost estimate $128 – 149 million (FY2009-18)**

U.S. SMR/NGNP Market 2020-50

Source: INL/EXT-10-19037



SMR INSIGHTS - SUMMARY

- **In the 1950's and 60's there existed a great number of more or less exotic/innovative reactor designs – all were Small or Medium size prototypes (but not modular), which eventually consolidated into the three (BWR, PWR, HWR) large size commercial NPP designs today**
- **Today a 'second wave' of many familiar, innovative and/or exotic SMR designs are arriving – many created by enthusiastic newcomers and focusing on the multi-modular NPP concept**
- **High entry barriers and harsh market forces (methods, verification, licensing, new infrastructure costs, etc) will again force consolidation, and only very few SMR designs based on familiar technologies can become commercially viable in the near term**
- **SMR standardization, factory-based replication and multi-modular NPP design - and alliances with large existing/credible NPP Vendors will be key success factors - for a few surviving future SMRs**


Thank You!
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