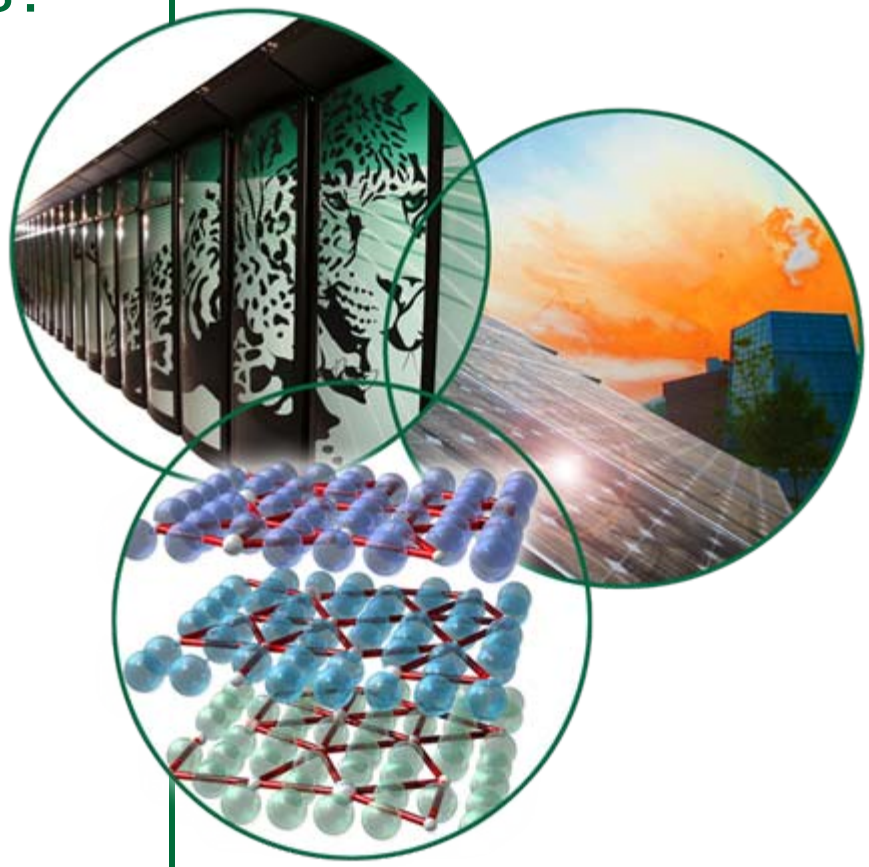
Small Nuclear Reactors: Promises and Pitfalls



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U.S. DEPARTMENT OF ENERGY

OAK RIDGE NATIONAL LABORATORY
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Suppose you need to buy a new car…

H1 Hummer

EPR
(1600 MWe)

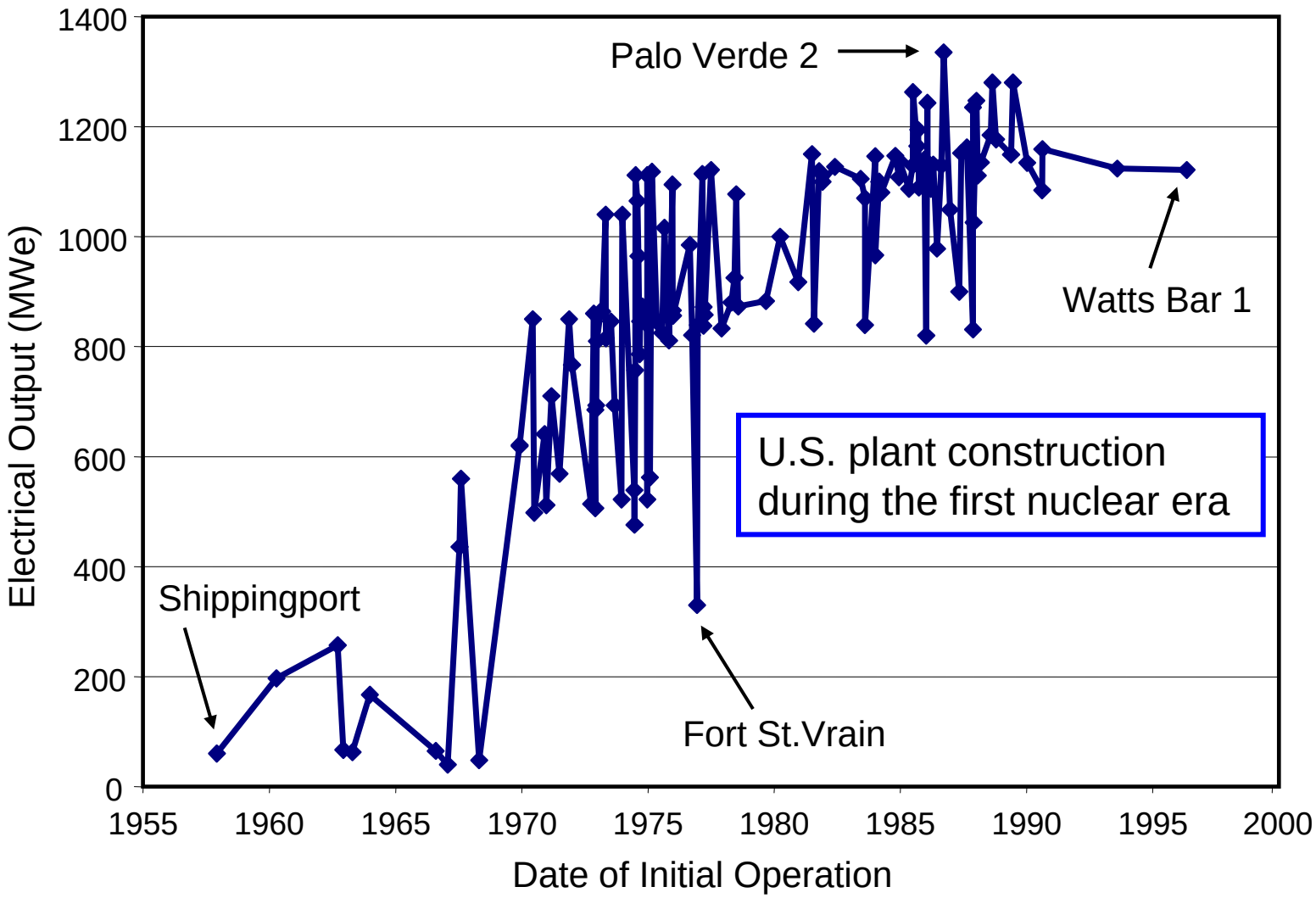
Cadilac
Escalade

AP-1000
(1150 MWe)

Smart Car

?

The U.S. Initially Built Smaller Sized Commercial Nuclear Power Plants



Weinberg Study* (1985) Introduced Notion of Deliberately Small Reactors

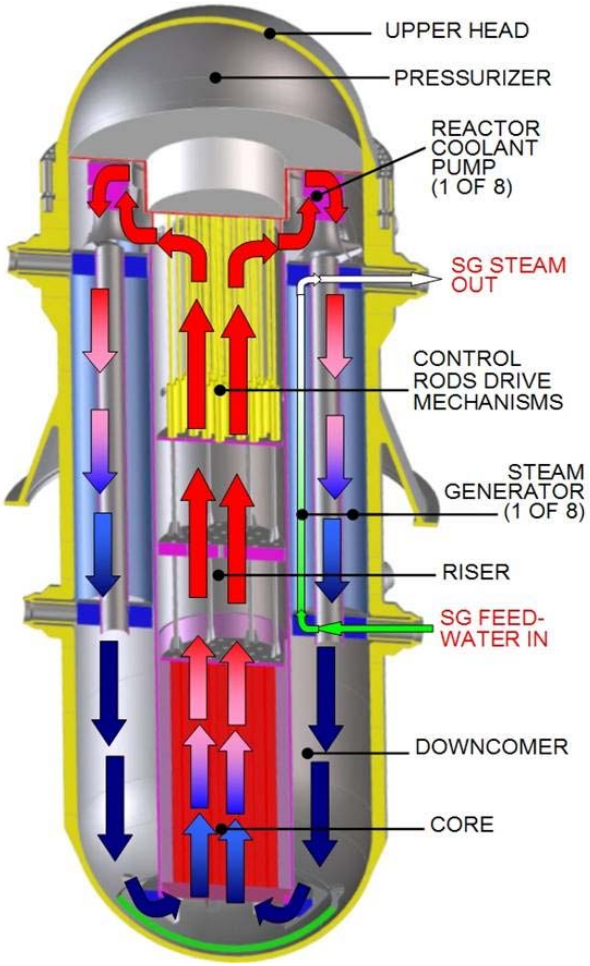
- **Motivated by lessons learned from the *first nuclear era***
- **Explored emerging reactor designs that were inherently more forgiving than large LWRs**
- **Main findings:**
  - **Post-TMI LWRs pose very low risks to the public but investor risks and high and uncertain capital cost limit market viability**
  - **Large LWRs are too complex and too sensitive**
  - **"Inherently safe" concepts are possible and should be pursued, such as:**
    - **The Process Inherent Ultimately Safe (PIUS) reactor**
    - **The Modular High-Temperature Gas-Cooled Reactor (MHTGR)**

*A. M. Weinberg, et al, *The Second Nuclear Era*, Praeger Publishers, 1985

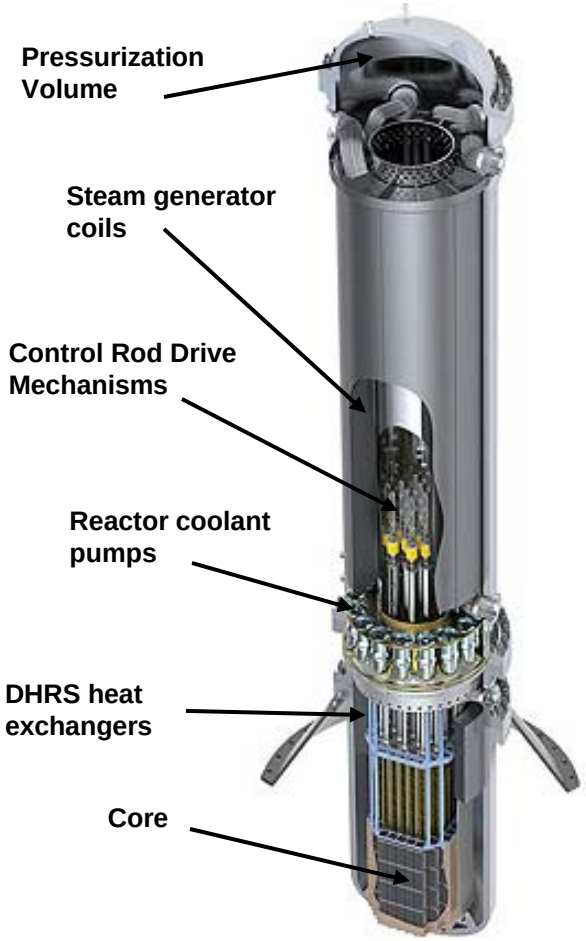
Sampling of SMR Concepts Under Development World-Wide

- **Integral PWR:** CAREM (Ar), IMR (Jp), IRIS (US), NuScale (US), mPower (US), SCOR (Fr), SMART (RoK)
- **Marine derivative PWR:** ABV (RF), KLT-40S (RF), NP-300 (Fr), VBER-300 (RF)
- **BWR/PHWR:** AHWR (In), CCR (Jp), MARS (It)
- **Gas-cooled:** GT-HTR-300 (Jp), GT-MHR (US), HTR-PM (Ch), PBMR (SA)
- **Sodium-cooled:** 4S (Jp), BN-GT-300 (RF), KALIMER (RoK), PRISM (US), RAPID (Jp)
- **Lead/Pb-Bi-cooled:** BREST (RF), ENHS (US), LSPR (Jp), STAR/SSTAR (US), SVBR-75/100 (RF)
- **Non-conventional:** AHTR (US), CHTR (In), Hyperion (US), MARS (RF), MSR-FUJI (Jp), TWR (US)

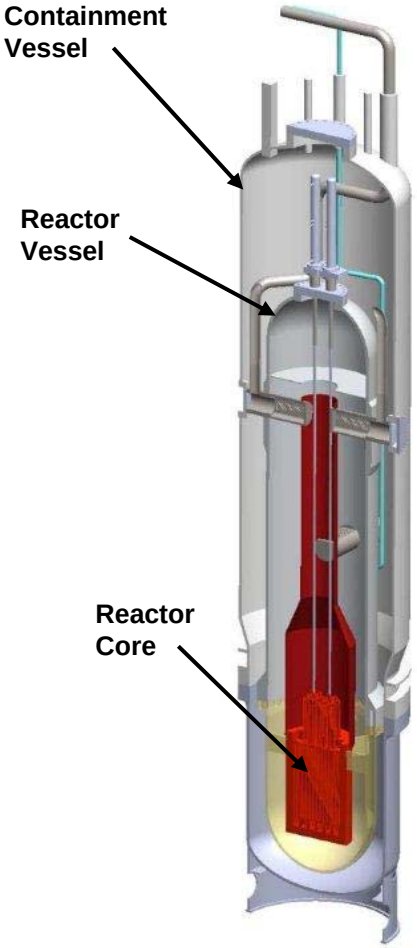
LWR-Based SMR Designs Under Development in U.S.



IRIS (Westinghouse)

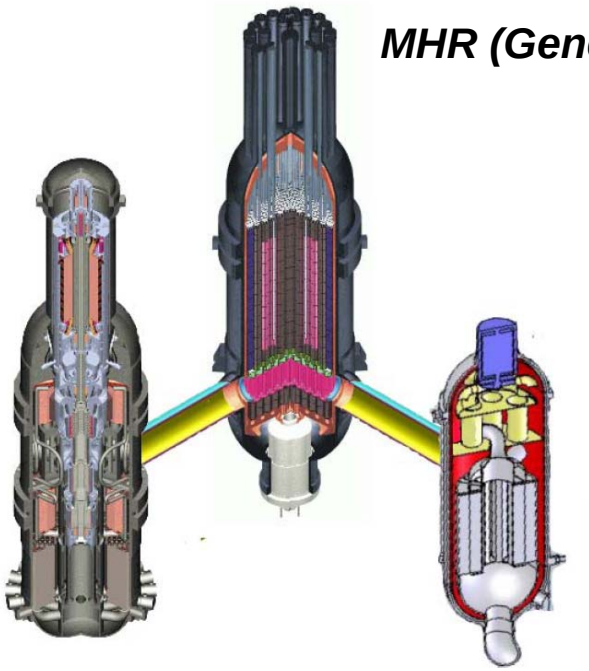


mPower (Babcock & Wilcox)

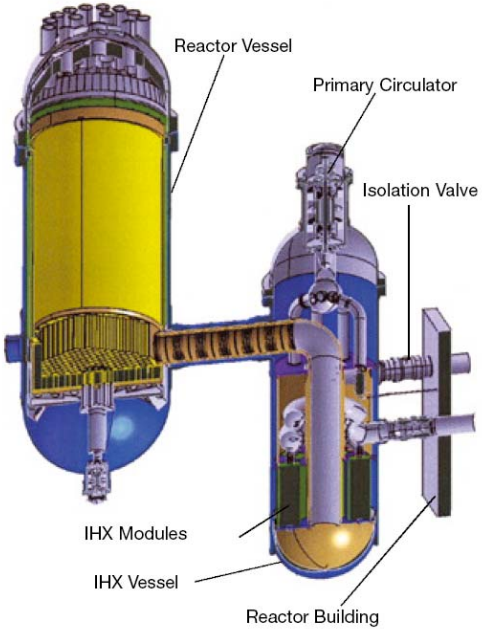


NuScale (NuScale)

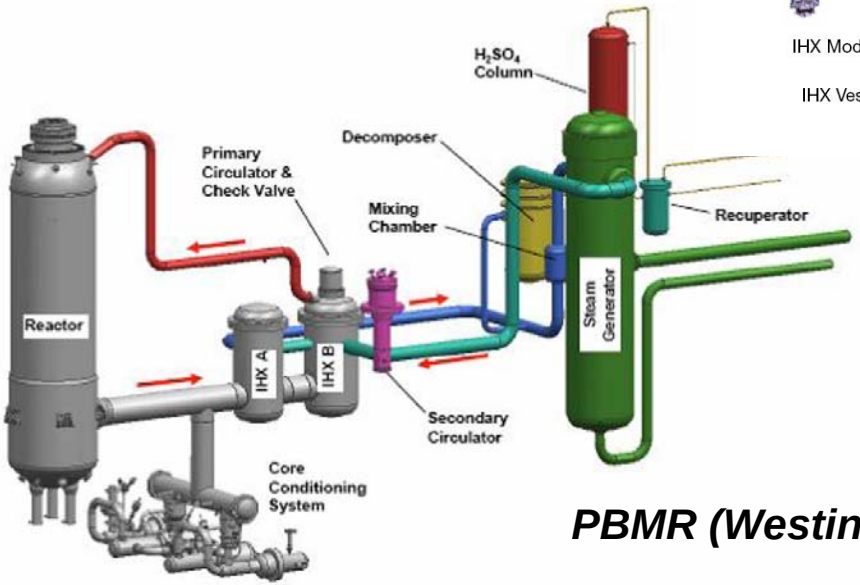
Gas-Cooled SMRs (NGNP options)



MHR (General Atomics)

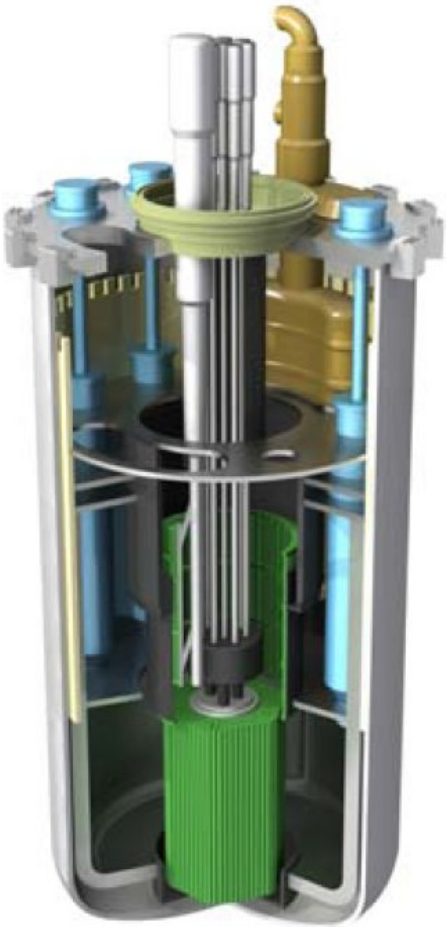


ANTARES (Areva)

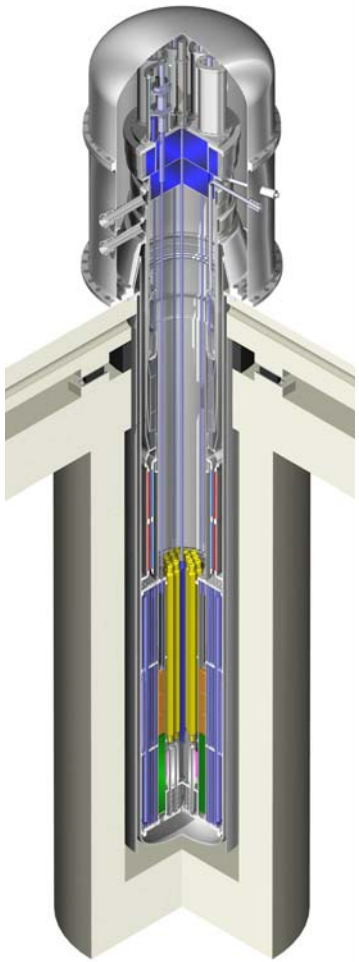


PBMR (Westinghouse)

Liquid-Metal-Cooled SMRs



PRISM (General Electric)



4S (Toshiba/W)

Hyperion (Hyperion)

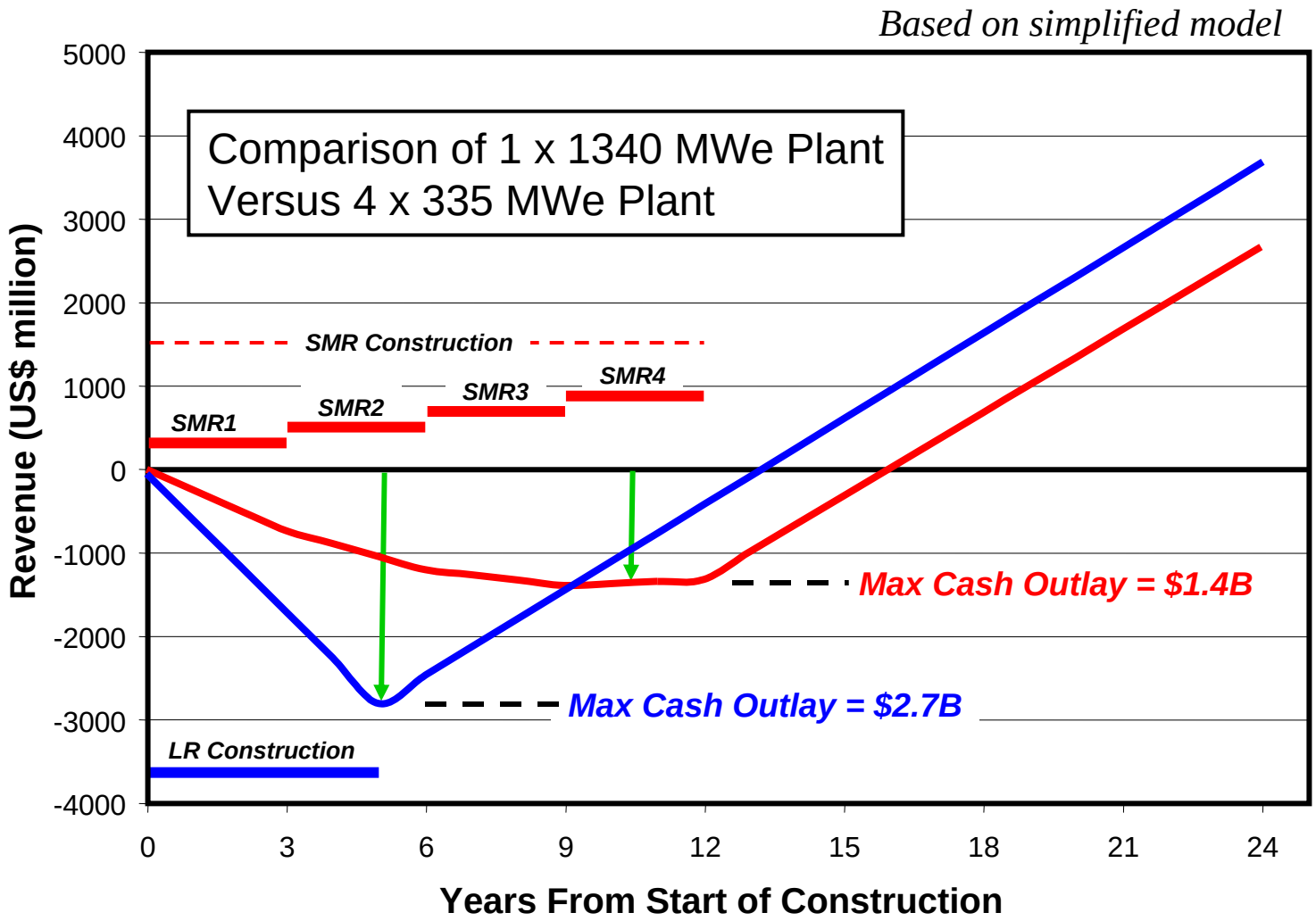
Interest in Smaller Sized Reactor Designs Are Beginning To (Re)Emerge

- **Benefits**
  - **Cheaper (capital outlay)**
  - **Improved fabrication and construction logistics (especially domestic)**
  - **Enhanced safety (robustness)**
  - **Operational flexibilities (broader applications)**
- **Applications**
  - **Smaller utilities**
  - **Countries with financing or infrastructure constraints**
  - **Distributed power needs (e.g. military base islanding)**
  - **Non-electrical (process heat) customers**

Economic Benefits

- **Total project cost**
  - **Smaller plants should be cheaper**
  - **Improves financing options and lowers financing cost**
  - **May be the driving consideration in some circumstances**
- **Cost of electricity**
  - **Economy-of-scale (EOS) works against smaller plants but can be mitigated by other economic factors**
    - **Accelerated learning, shared infrastructure, design simplification, factory replication**
- **Investment risk**
  - **Maximum cash outlay is lower and more predictable**
  - **Maximum cash outlay can be lower even for the same generating capacity**

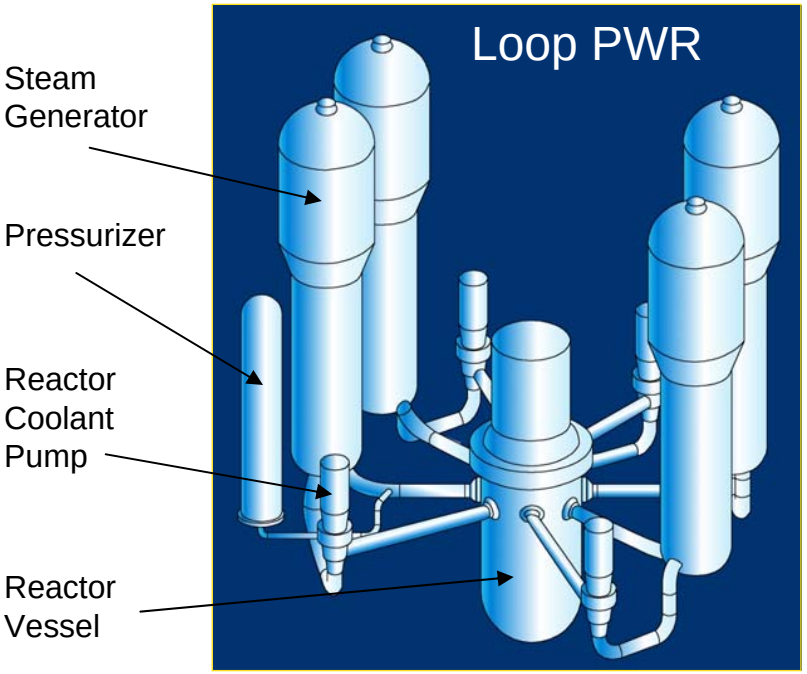
Staggered Build of SMRs Reduces Maximum Cash Outlay (*Source: B. Petrovic, GaTech*)

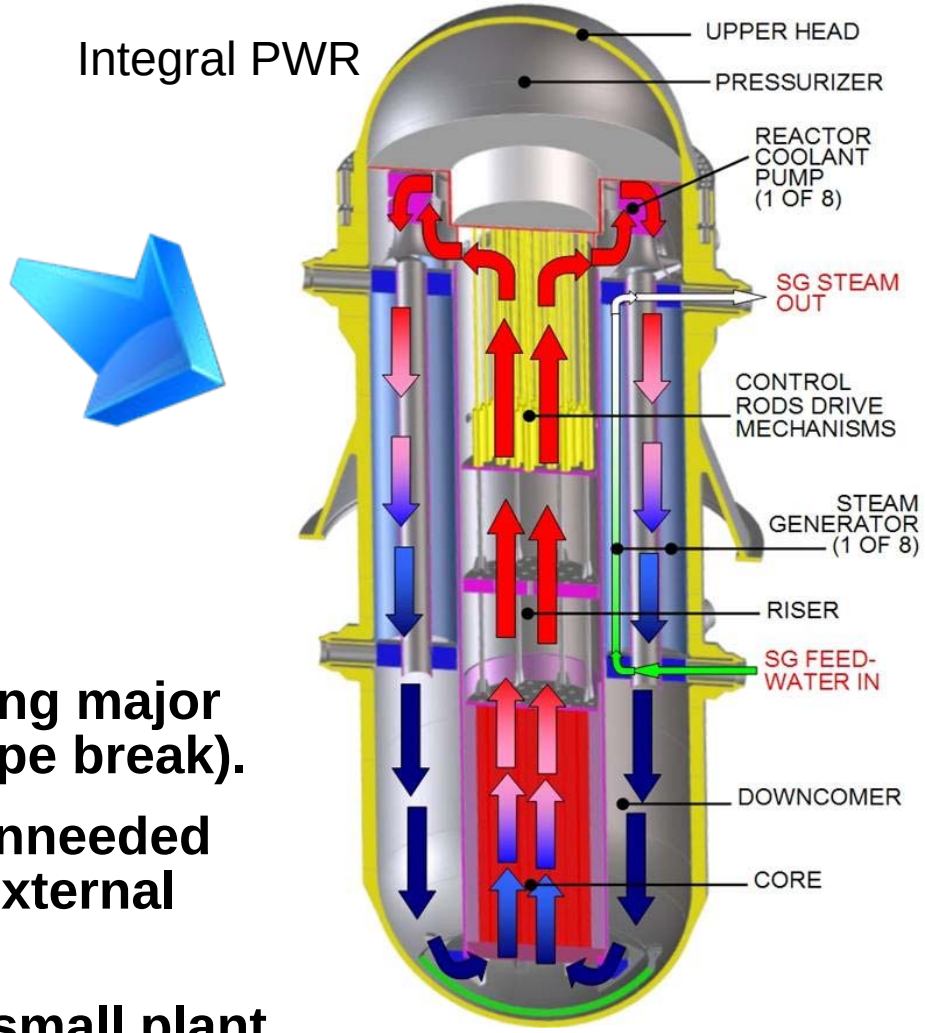


Safety Benefits of DSRs

- **Reduced source term**
  - **Lower power means fewer fission products produced**
  - **Can allow for increased margin, or reduced shielding, site radius, emergency planning zone, etc.**
- **Improved decay heat removal**
  - **Lower decay heat generated in the reactor core**
  - **More efficient passive decay heat removal from reactor vessel (volume-to-surface area ratio effect)**
- **Elimination of accident "opportunities"**
  - **No large pipes in primary circuit means no large-break loss-of-coolant accidents**
  - **Increased water inventory means slower system response to power transients**

Integral Primary System Configuration





- **Enhances robustness by eliminating major classes of accidents (e.g., large pipe break).**
- **Simplifies design by eliminating unneeded safety systems, large piping and external vessels.**
- **Allows for compact containment (small plant footprint) to enhance economics and security.**

SMR Applications

- **Electricity generation**
  - **Smaller utilities with low demand growth**
  - **Regions/countries with small grid capacity**
  - **Installations requiring independent power**
  - **Non-baseload possibilities**
- **Non-electrical power needs**
  - **Potable water production (desalination)**
  - **Advanced oil recovery (tar sands and oil shale)**
  - **Hydrogen production**
  - **Advanced energy conversion (coal-to-liquids, synfuels)**
  - **District heating**

SMR Challenges – Technical

- **All designs have some degree of innovation in components, systems, and engineering, e.g.**
  - **Integral primary system configuration**
  - **Internal control rod drive mechanisms and pumps**
  - **Multiplexed control systems/interface**
- **Longer-term systems strive for increased utility/security**
  - **Long-lived fuels and materials for extended operation**
  - **Advanced designs for load-following and co-generation**
- **Sensors, instrumentation and controls development are likely needed for all designs**
  - **Power and flow monitoring in integral systems**
  - **Advance prognostics and diagnostics for remote operations**
  - **Control systems for co-generation plants**

SMR Challenges – Institutional

- **Too many competing designs**
- **Mindset for large, centralized plants**
  - **Fixation on economy-of-scale**
  - **Economy-of-hassle drivers**
  - **Perceived risk factors for nuclear plants**
- **Traditional focus of regulators on large, LWR plants**
  - **Standard 10-mile radius EPZ (in the U.S.)**
  - **Staffing and security force size**
  - **Plant vs module licensing**
- **Fear of first-of-a-kind**
  - **New business model as well as new design must be compelling**

SMR Simulation "Opportunities"

- **Many Mod&Sim benefits are shared with large plants**
  - **Improved performance through reduced design margins and more rapid insertion of new technologies**
  - **Expedited deployment through improved licensing review process**
- **Some issues are more specific to SMRs**
  - **Impacts of reactor compactness (more tightly coupled)**
  - **Development of new designs with new materials and physics**
  - **Validation of new engineering on safety performance**
  - **Impacts of different use (co-generation, power islanding, etc.)**
  - **Reactor health for extended operation without refueling**

Summary

- **The U.S. started commercial nuclear power using smaller sized plants**
- **After initial experience with small units, plant size and complexity grew rapidly**
- **New SMRs offer many potential benefits**
- **SMRs do not compete directly with large plants—they offer customers a greater range of options**
- **They offer some unique simulation challenges**

THINK SMALL !

"Deliberately Small Reactors and the Second Nuclear Era,"
Progress in Nuclear Energy, **51**, p 589-603 (May-June 2009).