Next Generation of NPPs in the United States

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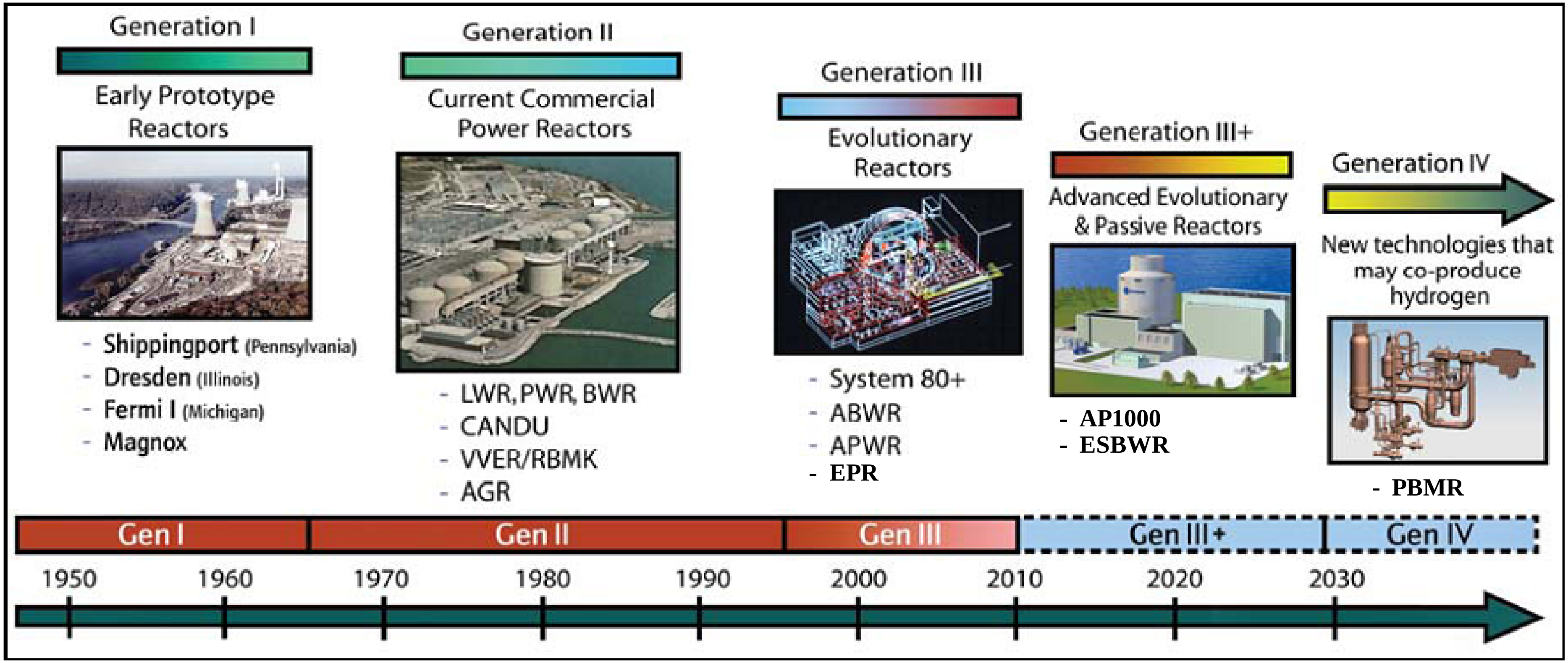
The U.S. Nuclear Regulatory Commission published safety goals for nuclear power in 1986

- "The risk to an average **individual** in the vicinity of a nuclear power plant of **prompt** fatalities that might result from reactor accidents should not exceed one-tenth of one percent (0.1 percent) of the sum of prompt fatality risks resulting from other accidents to which members of the U.S. population are generally exposed."

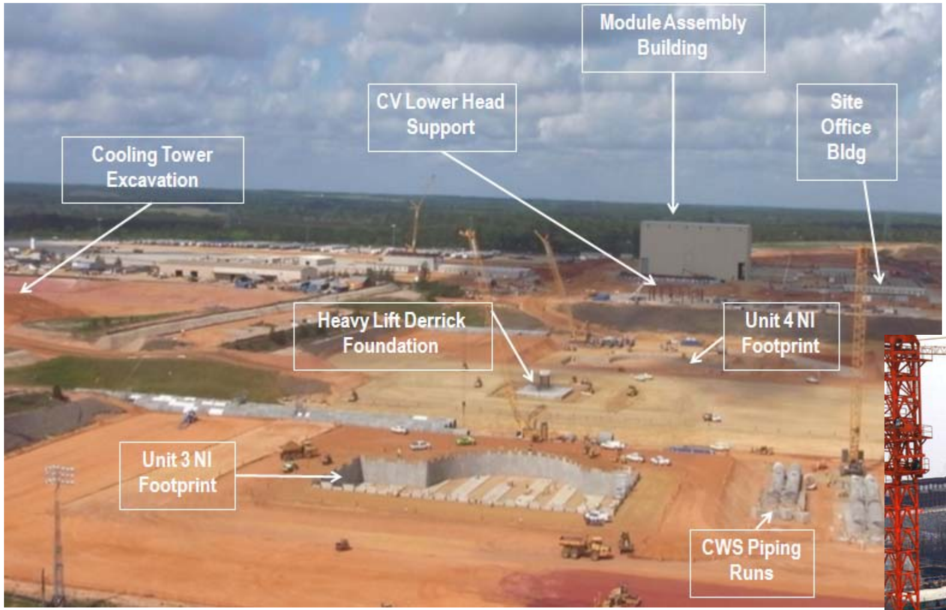
- "The risk to the **population** in the area near a nuclear power plant of cancer fatalities that might result from nuclear power plant operation should not exceed one-tenth of one percent (0.1 percent) of the sum of cancer fatality risks resulting from all other causes."

U.S. nuclear power regulation is largely performance based

Evolution of Nuclear Power



The first new U.S. nuclear construction in 30 years will be Westinghouse AP1000 reactors



Vogtle Units 3 & 4 now in early stage of construction in U.S. with LWA

Four units now well into construction in China

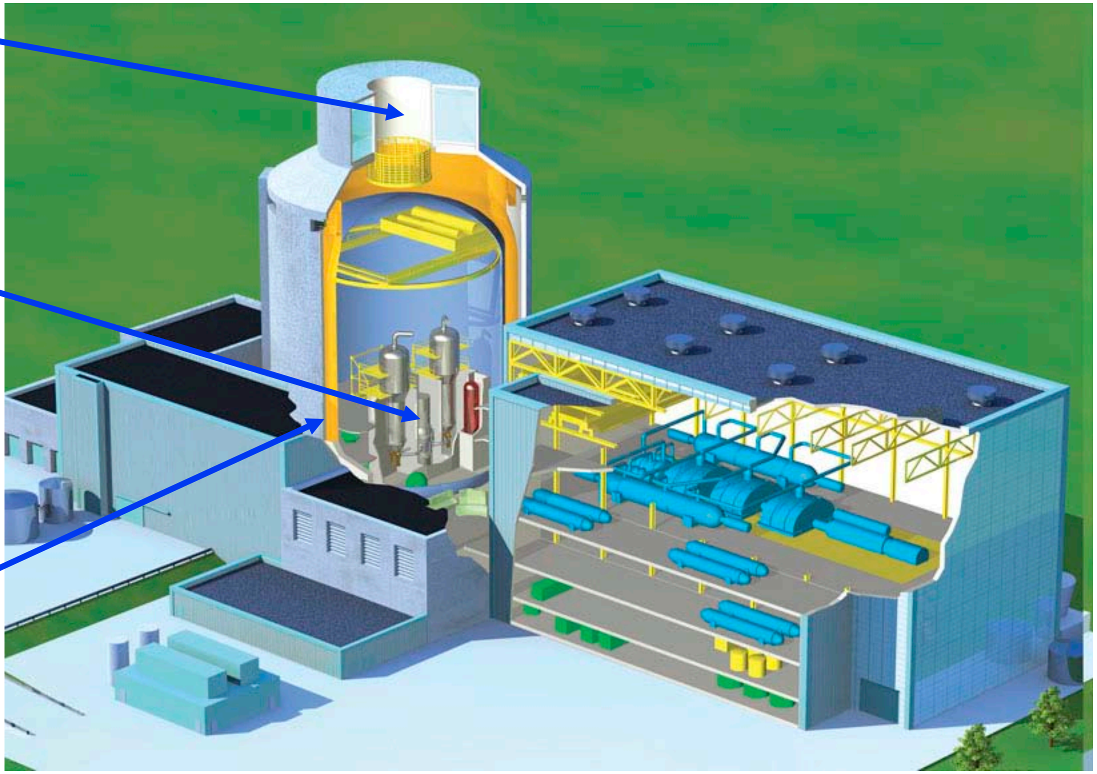
New nuclear construction will use Gen III+ and Gen IV technologies that have greater resilience for extreme external events

The AP-1000 illustrates many of the best practices for Gen III+

Ambient air provides ultimate heat sink for decay heat removal

Decay heat removed using natural circulation without A/C power

Steel/concrete composite structures provide ductile response under beyond-design-basis loading



Small Modular Reactors: NuScale example

Natural Convection for Cooling

- Inherently safe natural circulation of water over the fuel driven by gravity
- No pumps, no need for emergency generators

Seismically Robust

- System is submerged in a pool of water below ground in an earthquake resistant building
- Reactor pool attenuates ground motion and dissipates energy

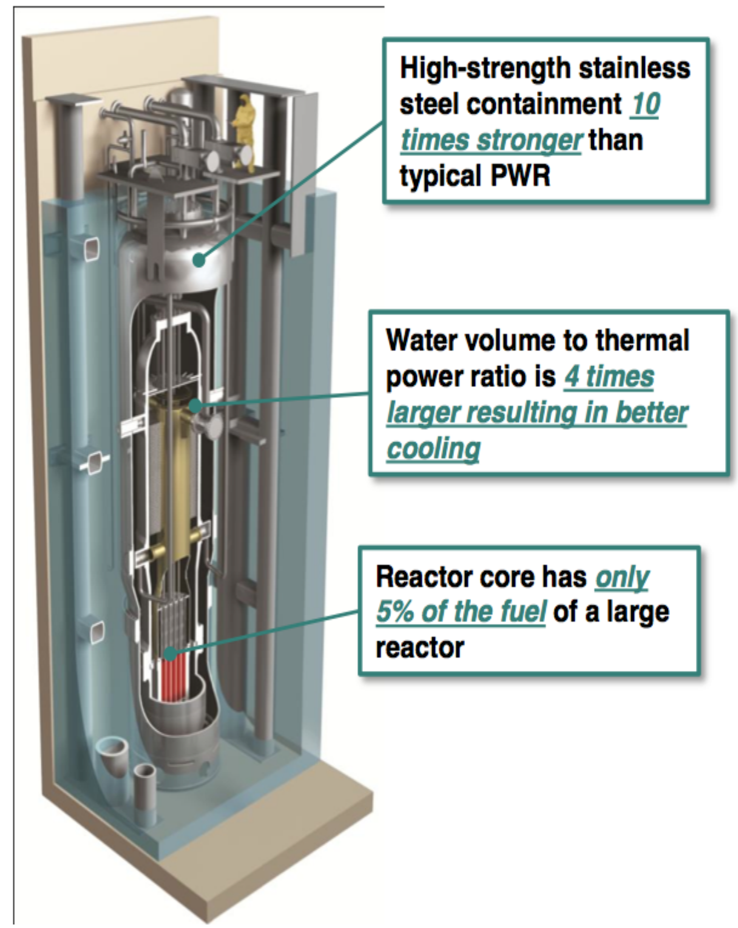
Simple and Small

- Reactor is 1/20th the size of large reactors
- Integrated reactor design, no large-break loss-of-coolant accidents

Defense-in-Depth

- Multiple additional barriers to protect against the release of radiation to the environment

45 MWe Reactor Module

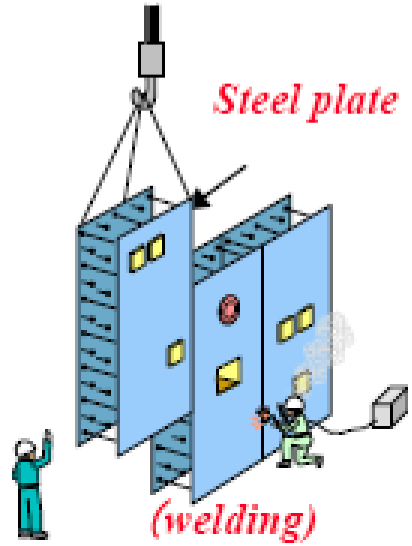


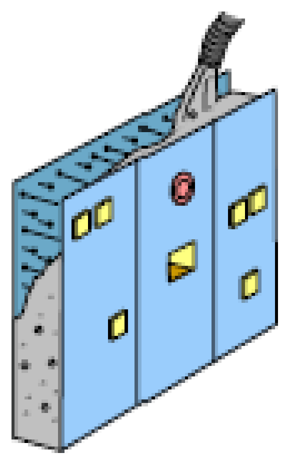
Steel plate reinforcement creates a more ductile reinforced structure that gives controlled response under beyond-design-basis loading

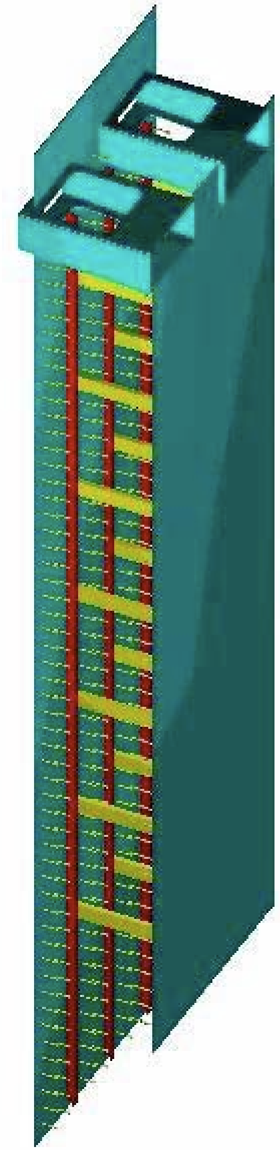
- **Steel plate contains failed concrete, which retains significant compressive strength**
- **Adopted by AP-1000 to upgrade containment for aircraft crash, 2-month construction schedule savings**

Steel-plate sandwich wall construction als facilitates modular, rapid fabrication

- **Steel plate used as:**
  - Form
  - Reinforcement
- **Modular, prefabricated components**
- **Rapid construction**
  - Eliminates set up and tear down of plywood framing



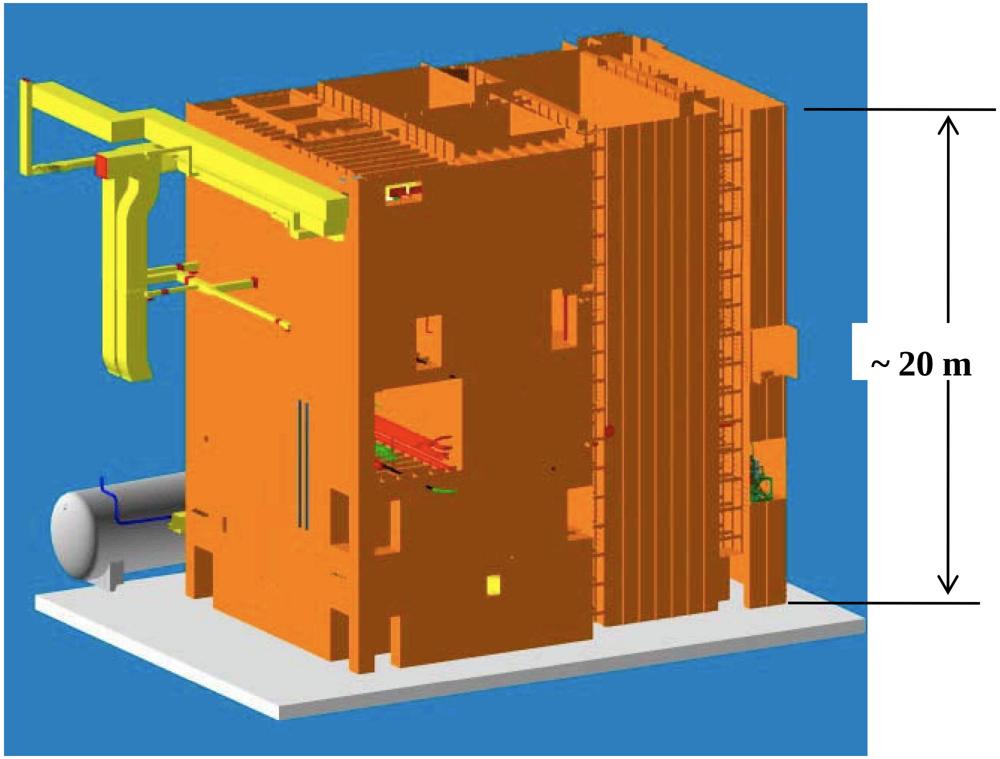




AP-1000 Structural Submodule

Automated factory fabrication of AP-1000 building structural modules in China (Shaw building similar plant now in Lake Charles, LA)

AP-1000 Fuel Handling Building being set in place in Sanmen, China

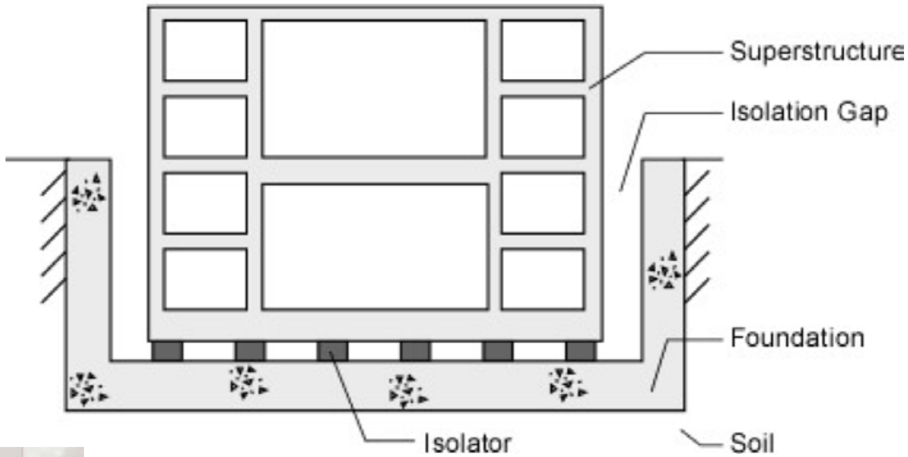


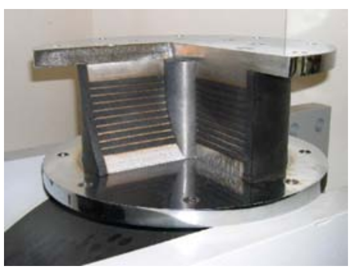
770-ton AP-1000 auxiliary building module, assembled from factory prefabricated plate components, being set in place onto foundation, Sanmen, China, July 2009

It is important to consider aircraft crash requirements early in design

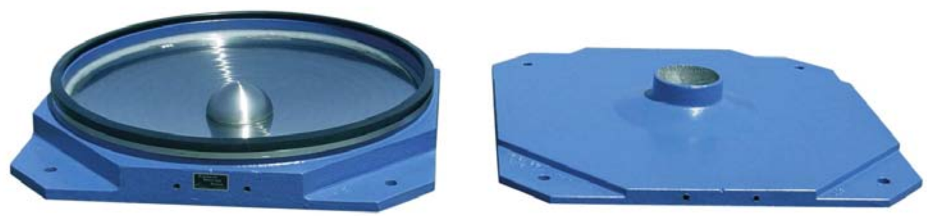
Lucas Heights reactor, Australia, with a steel-girder external event shield

Seismic Base Isolation





Laminated Rubber Isolator



Friction Pendulum Isolator

- **Filters out high-frequency ground motion**
- **Building oscillates with isolated period (1.5 – 3.0 sec), higher frequency ground motion is filtered out**

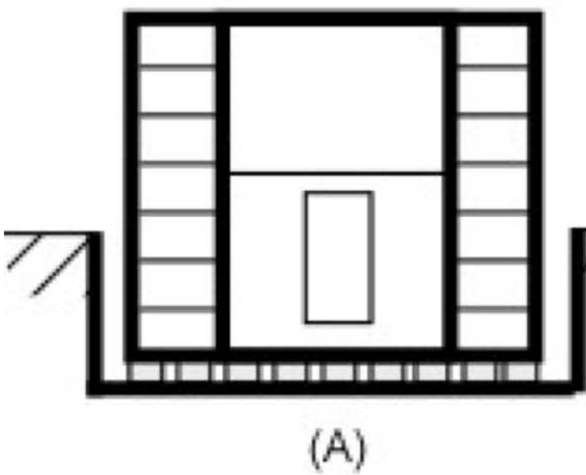
Conventional LWR reactor buildings are heavy

Reactor	Concrete (m^3)	Steel and Iron (metric tons)	Total Weight (metric tons)
1970's PWR (1000 MW)	22,600	7,500	59,500
ABWR (1350 MW)	67,500	18,500	174,000
EPR (1600 MW)	61,900	18,500	161,000
ESBWR (1500 MW)†	29,200	8,900	76,000

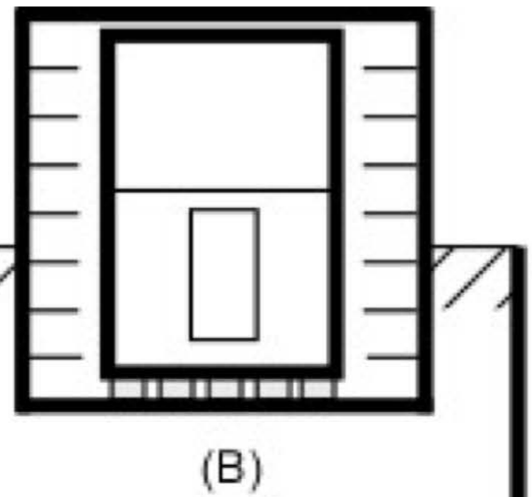
† The ESBWR underwent a substantial structural redesign that increased its weight from the value shown here.

- **One design option for modular reactors is to couple the external event shield to the base-isolated foundation**
  - **Total mass of building is important in affecting the response to large aircraft crash**

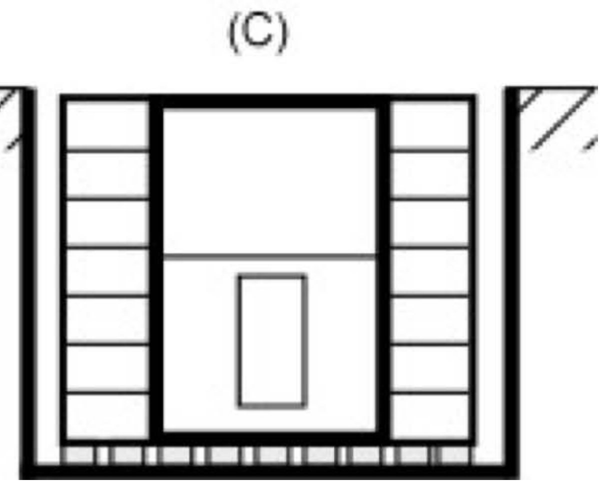
Major Options for Modular Reactor External Event Shell Design



Above-grade, coupled event shell and reactor citadel



Above-grade, decoupled event shell and reactor citadel



Fully below-grade construction

Structural design must be integrated with reactor safety/security systems

- **Physical arrangement is important for multiple functions**
  - **Personnel access control (safety and security)**
  - **Emergency response**
  - **Ventilation and contamination control**
  - **Radionuclide containment during accidents**
- **Important design interfaces exist with multiple SSC's**
  - **Cranes**
  - **Piping (particularly "umbilicals" across base-isolation gap)**
  - **Electrical (multiple sources)**
  - **HVAC**
  - **I&C**
  - **Fire protection system**
  - **Component cooling systems/passive decay heat removal**

Some general design principals

- The biological shielding and missile shielding required in the reactor citadel can be used to increase physical security (access control) for passive safety equipment and nuclear materials
  - Take advantage of the fact that routine personnel access is not needed to make these volumes (e.g. no routine access, access only by crane-movable hatches)
- Volume between citadel and event shell may be used to house redundant, safety related equipment (e.g. batteries)
  - Can provide physical isolation by locating equipment trains at different quadrants of the building
  - Design must accommodate base isolation gap between shell and citadel
- Other design principals discussed in UCB reports