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# Modularity-at-scale for advanced reactors presentation

August 2022

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Changing the World's Energy Future


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**August 2022**

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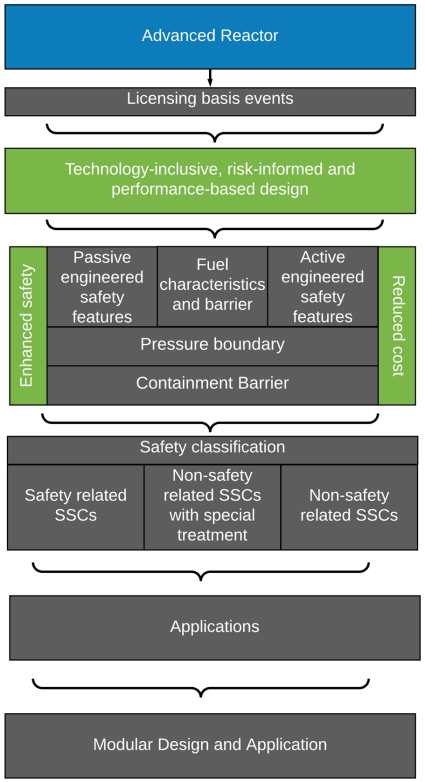
# Modularity-at-scale for advanced reactors

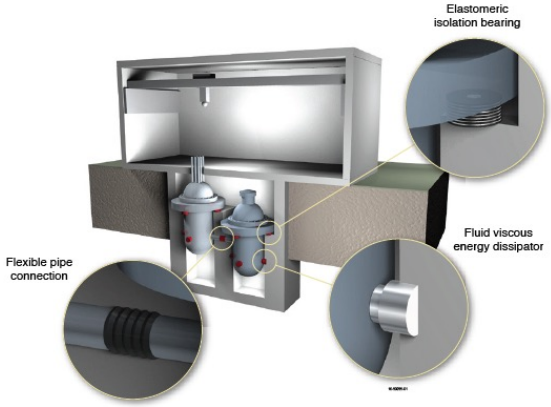
Idaho National Laboratory

# Introduction

- Nuclear energy has been challenged during the deployment of new builds.
- Emerging new regulations are providing flexibility in how we may design next-gen plants.
- Design in flexibility provides new opportunities to have cost effective and time efficient deployments.
- New modular designs and engineering have the potential to streamline the generation of nuclear deployments

# New Regulations



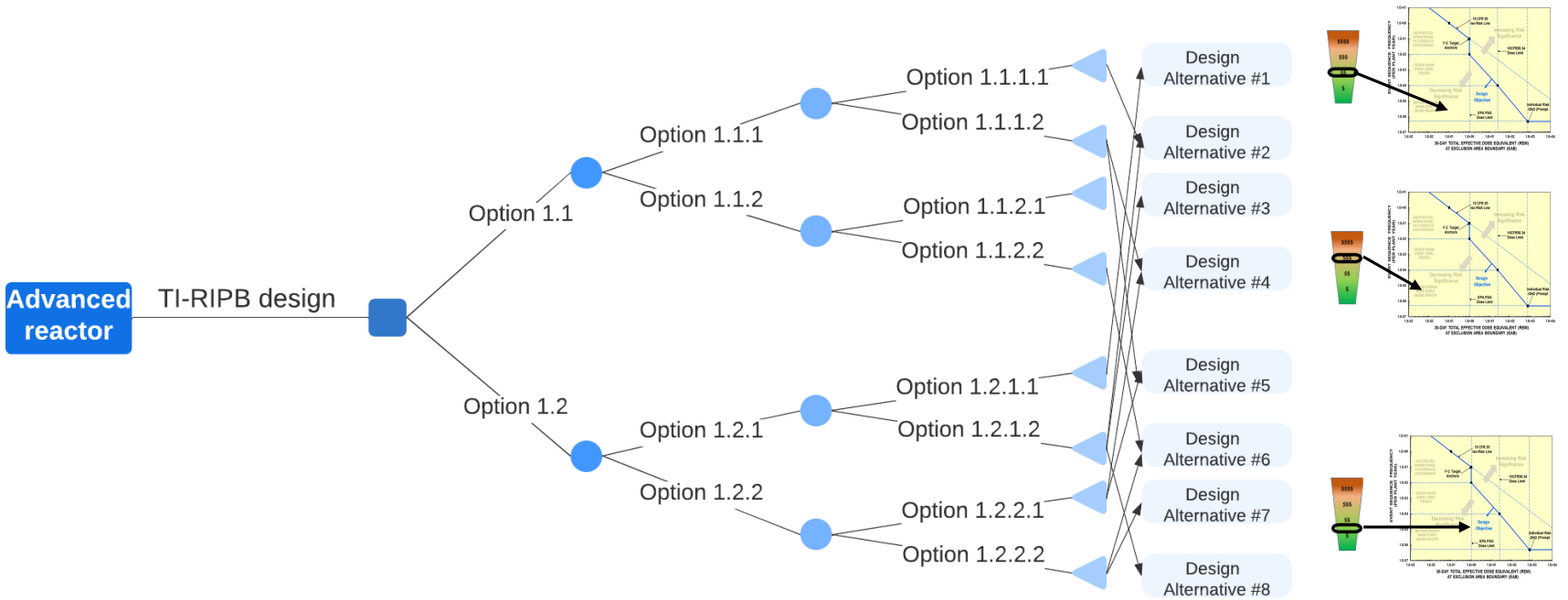




Seismic isolators, MIT, 2018

Modular deployment, Tesla Gigafactory

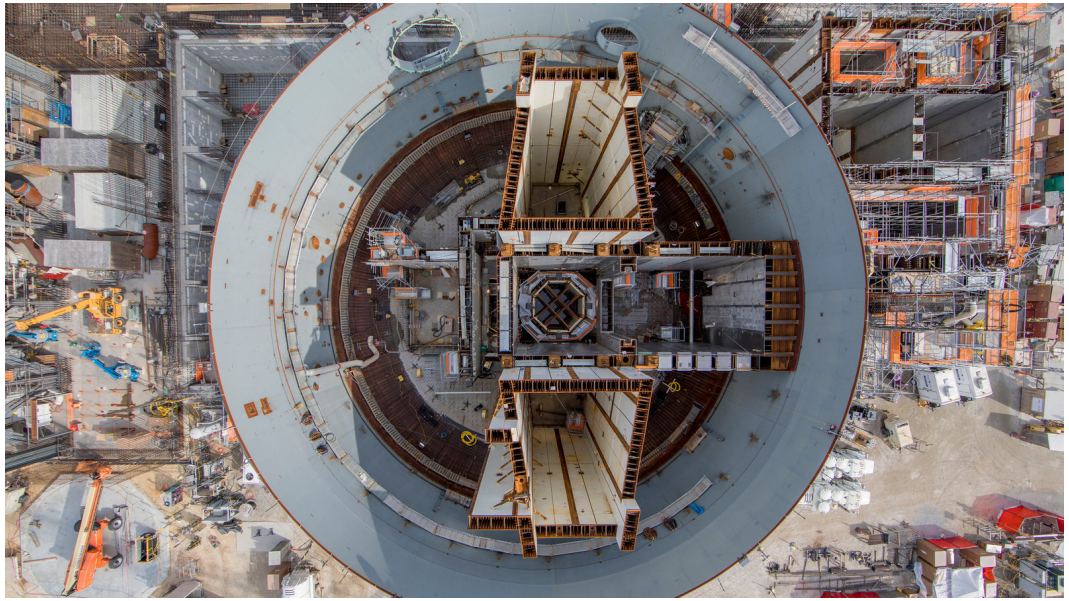
Deeply embedded structures, Ultra Safe Nuclear Corp. (USNC)

# Flexible design



# Conventional Nuclear Deployment

| | Barakah Units 1-4 | Burj Khalifa |
|---|---|---|
| Volume of concrete (cubic yards) | ~2,800,0000 | ~430,000 |
| Man-hours | ~123,000,000 | ~22,000,000 |
| Total cost | $24.4 billion | $1.5 billion |



A view into Unit 4 at the Alvin W. Vogtle generating station in Georgia. (New York Times)

# Definitions

- DEFINITION:  Modularity can include…
  - incorporation of all major safety-significant systems within one module,
  - standardized modules,
  - factory fabricated modules,
  - the capacity to add modules to increase power output,
  - consolidation of components resulting in less on-site construction.
- Historically, modularity has been limited to the balance of plant for large-scale nuclear plants, such as steel-plate composite walls.
- Looking forward, modularity is now a hot topic in the commercial nuclear energy sector due to the emergence of small modular reactors.

# Modularity for different scales of nuclear deployment

1. A large Nuclear Power Plant (NPP) combines multiple, large-scale independent reactor units to increase the capacity or scale of the NPP, which share a common infrastructure.

2. A Small Modular Reactor may combine within a plant, two or more small- to medium- scale reactor units/modules.

3. Modularity of common site structures (Balance of Plant), conversion units, and other facilities (needed to various degrees for all sizes of reactors).

# Advantages

1. Reducing the share of the reactor built on-site (independently built) vs. fabricated in a shop (possibly in series with other units). Reducing the management and complexity of site work.
2. Improving learning by building a large number of smaller modular plants that can benefit from additional NOAK learning effects and reduced per-unit module costs.
3. Gaining direct labor work efficiencies including optimized labor use and coordination of trades, by building modules in controlled environments, using equipment that can accurately duplicate operations, and using standardized shop and quality processes.
4. Shortening construction schedules through parallel construction that allows field work to progress on-site while modules are factory built then delivered to the site when needed. Reduces indirect and management costs, direct cost contingencies and owner's costs.

# Advantages

5. Achieving cost savings from robotics and automation allowing computer-aided manufacturing that integrates design changes with manufacturing processes to minimize the design cycle and create tooling to produce modules faster with increased product quality.
6. Reducing annualized costs though modules designed to reduce operational and maintenance requirements through simplifying and standardizing service requirements and allowing quick replacement of modular components with a minimum of operational downtime.

# Historical Lessons-Learned and Limitations of Modularity

- Large NPPs: Benefits of modularization for large NPPs were often not realized.
  - Modular SC-type construction requires demanding nuclear grade on-site activities (tight tolerances, welding, high qual concrete, difficulty to inspect, etc.).
  - Modularity unique to each NPP.

- SMRs: Designs require building out the entire plant to support multiple modules, but only operating a single reactors to begin.

- Micro Nuclear Reactors: For mass production to be realized, a few standardized reactor designs are needed.
  - Designs (HTRs, Fast Reactors, etc.)
  - Fuels (LEU, HALEU)
  - Reactor Module Sizes (scalable using same components)

# Modularity outside of the Nuclear Industry

- Modular designs and applications are widely used in automotive and aerospace industry, construction, data centers, software development, and others, examples include:
  - Google, LLC and Sun Microsystems developed modular data centers that are reported to cost a fraction of traditional centers.
  - Tesla's Gigafactory and the Apple Park Office use precast concrete structural elements produced in factories to speed construction.
  - Planet's Dove satellite (ex. NASA) uses a compact and modular unit that is easy to iterate on the previous designs.
  - SpaceX's Falcon 9 reusable rocket factory production process uses rapid prototyping and series production.

- Not all these technologies may satisfy the safety requirements (e.g., due to need for robust containment structure) or be compatible with each other (e.g., precast concrete for safety critical structures).

# Compatibility

| | Modular Precast Construction | | | Modular SC-type Construction | | |
|---|---|---|---|---|---|---|
| | Large-size plants | Medium-size plants | Micro-reactors | Large-size plants | Medium-size plants | Micro-reactors |
| LWR | | | | | | |
| HTGR | | | | | | |
| SFR/Thermal Microreactor | | | | | | |

Legend: Red=not compatible, Green=compatible, Yellow=marginally compatible

# Questions