Small Modular Reactors Update to ANS

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▪LA-UR 10-06424

What are Small Modular Reactors?

- Small - Less than 300 MW electric
- Modular
  - Some (if not all) of the reactor and plant is built in a factory.
  - Reactors that can be transported by truck or rail to a nuclear power site.
  - Additional modules can be added incrementally as demand for energy increases
- Simplicity of design

The DOE SMR Program

- The Department of Energy (DOE) believes that there is a need and a market in the United States for SMRs (DOE SMR brochure, February 2010)
- The DOE Office of Nuclear Energy's SMR program was developed to advance the licensing and commercialization of SMR designs
- Program kicked-off with a workshop in July 2010
- Anticipated funding:
  - FY11 – $39 million (currently at 55 million in house budget)
  - FY12 – $100 million
  - Future – $100 million or more

Primary Areas in the DOE SMR Program

- Licensing
- Fuel and Materials
- Computer Tools and Modeling for Design and Licensing (Present day issues)
- Large Scale Modeling (Future issues)
- Instrumentation and Control

Early Focus of SMR Program

- $20 Million to aid in the licensing effort of TWO of the light water reactor SMRs
- Some R&D targeted at helping the base technology and licensing issues associated with all types of SMRs
  - Re-examine size and requirements for emergency planning zones
  - Staffing requirements
  - Source term issues for multiple modules (reactors)
  - Security requirements
  - Risk informed licensing

Small Modular Reactors Vendors

generation mPower

NuScale Power

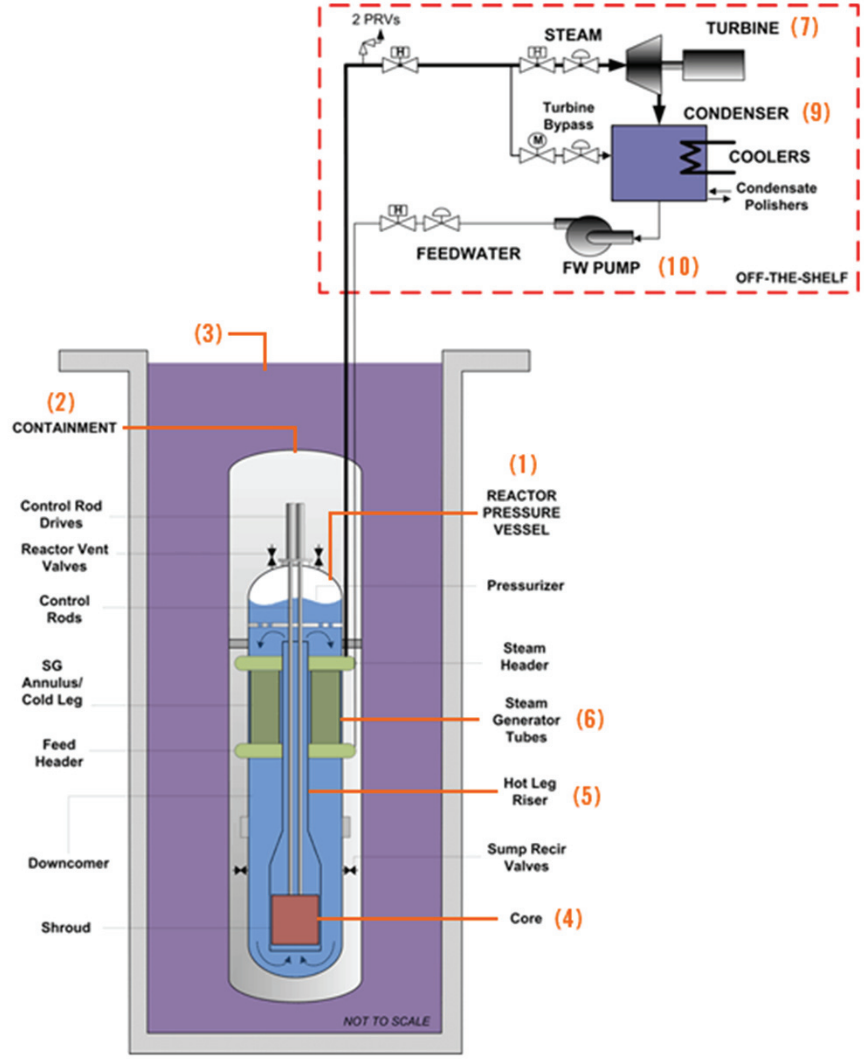
TOSHIBA
Leading Innovation >>>

TerraPower

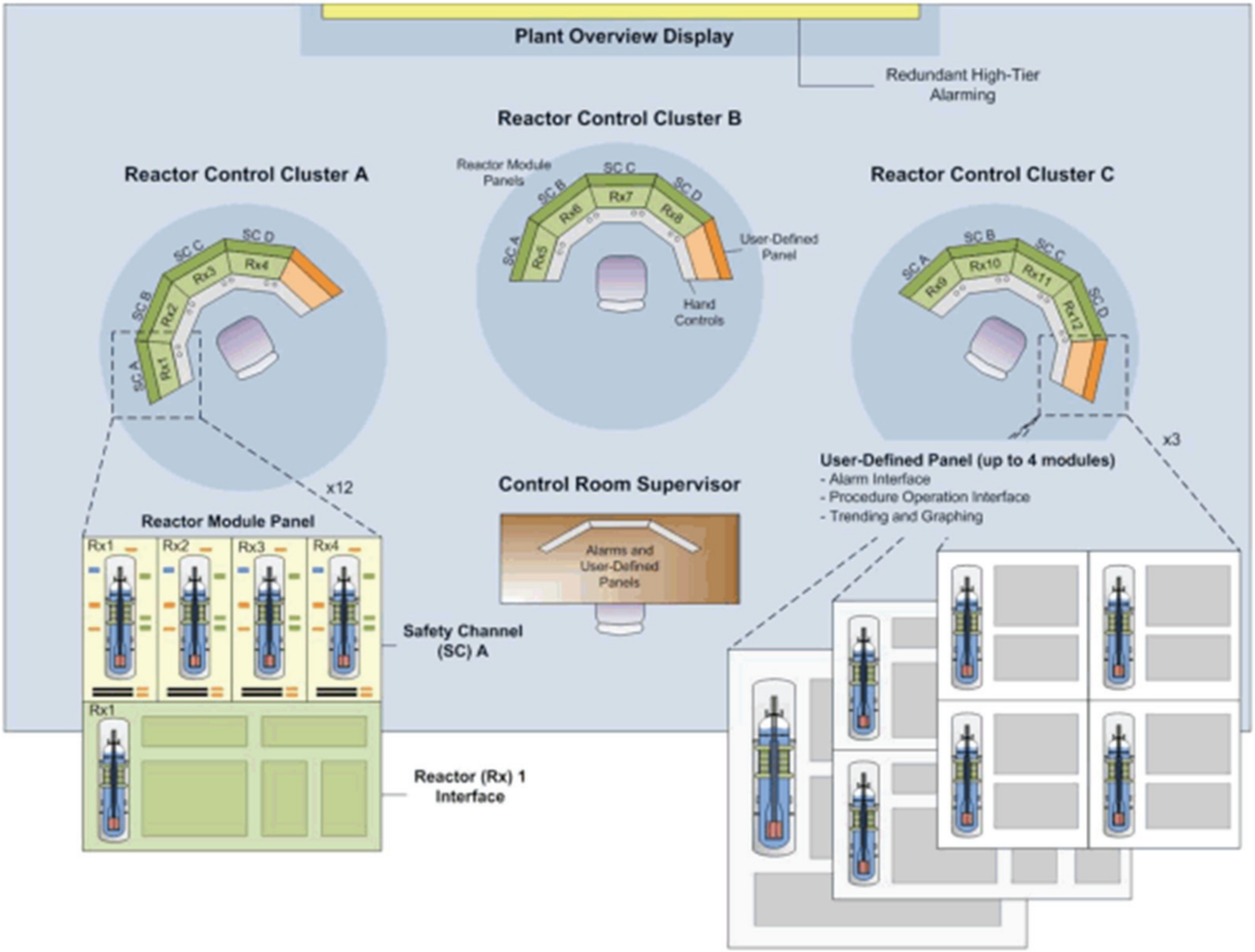
Hyperion Power
New Clear Energy

NuScale Power

- Small Pressurized Water Reactor with a “steel vessel” for containment (PWR in a can)
- 45 MWe, 150 MWt
- 1500 psi in vessel
- ~2/3 height standard PWR fuel bundle (17 x17, UO_2 fuel pin with zircalloy cladding)

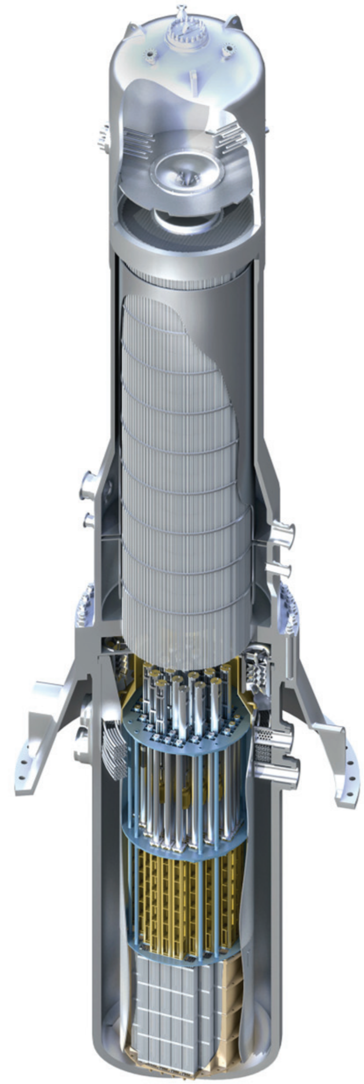


Key Element – Many Units = Lots of Power

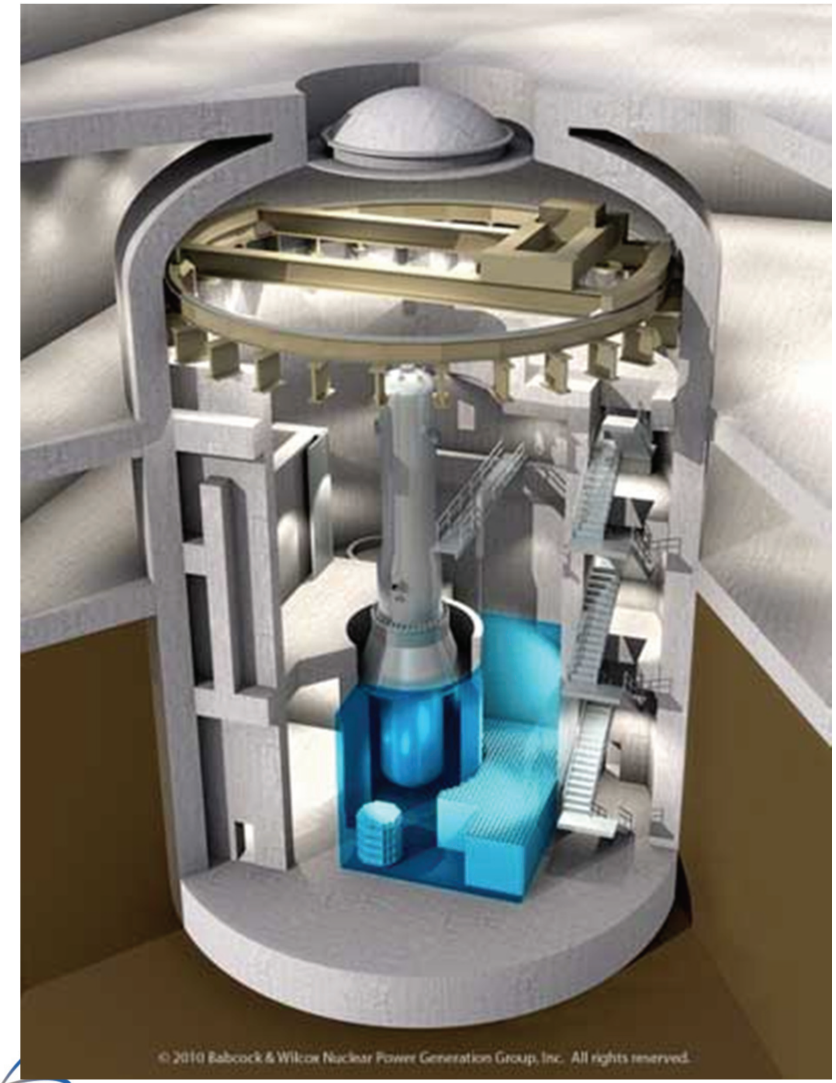


B&W mPower

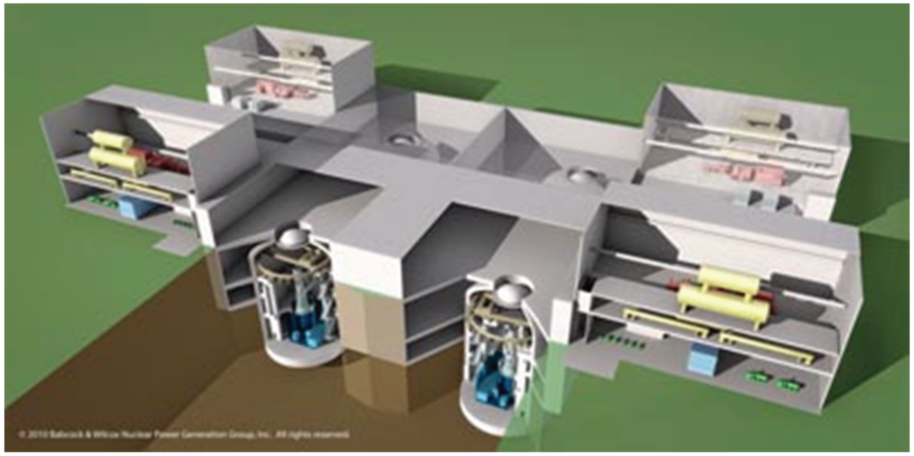
- 125 Mwe
- Pressurized Water Reactor
- Standard PWR fuel bundle
- Internal pumps and steam generator
- Control rods come in from the top



Multi-Module Units

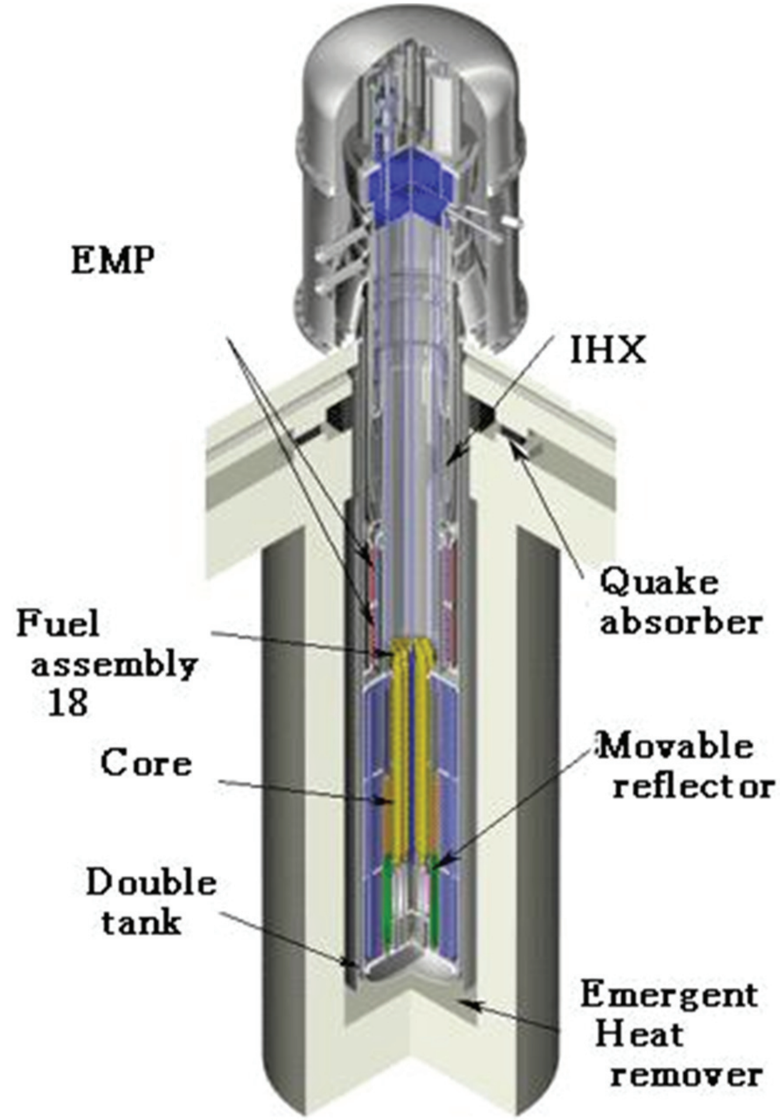


- Underground containment
- 1 to 10 Units
- Backed by large company



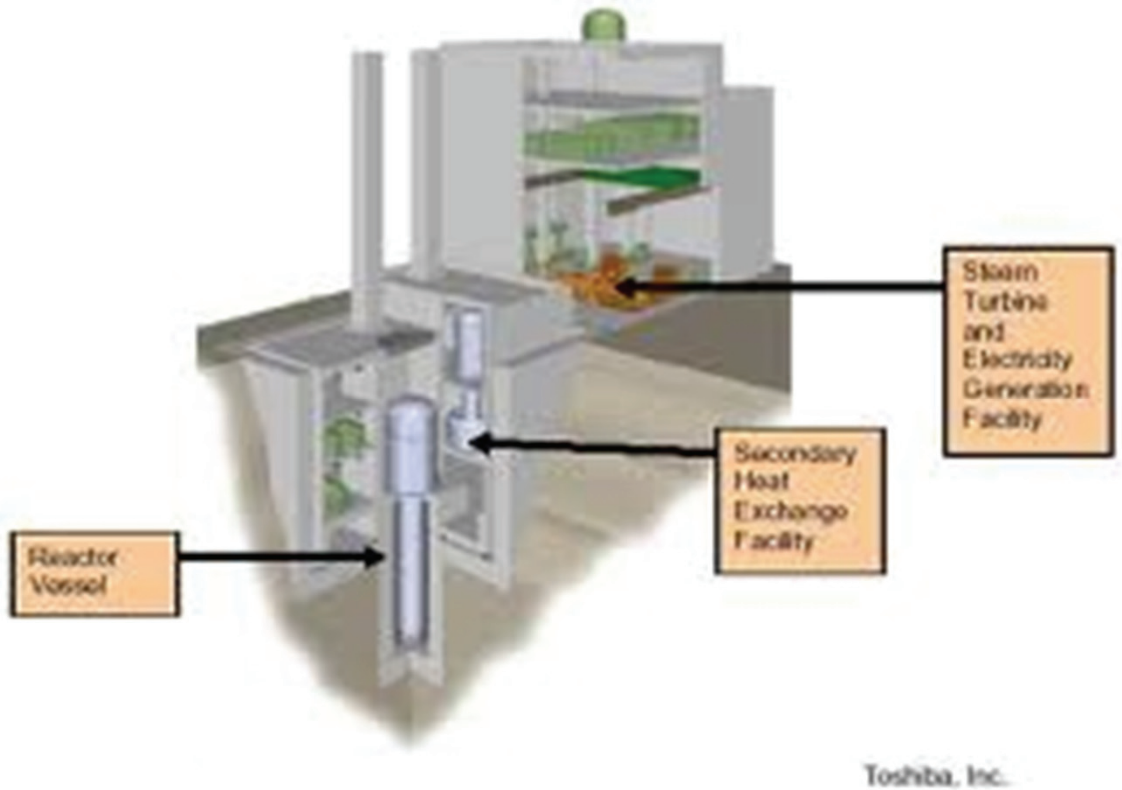
Toshiba – 4S

- Fast spectrum reactor
- Sodium cooled
- Metal fuel (uranium, zirconium alloy)
- 10 MWe (or in future 50 MWe)
- Based on experience of other metal reactors built worldwide (FFTF, EBR-II, Phenix, Monju)

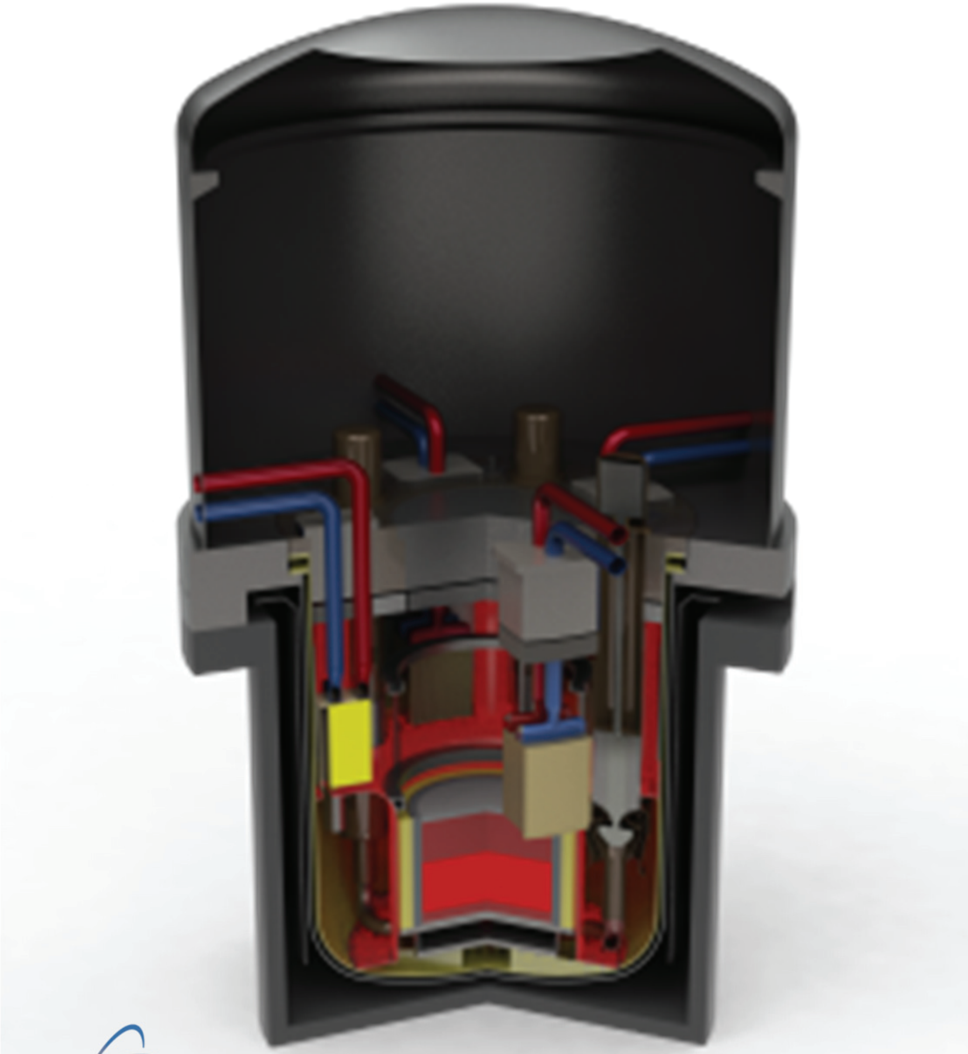


Features of 4S reactor

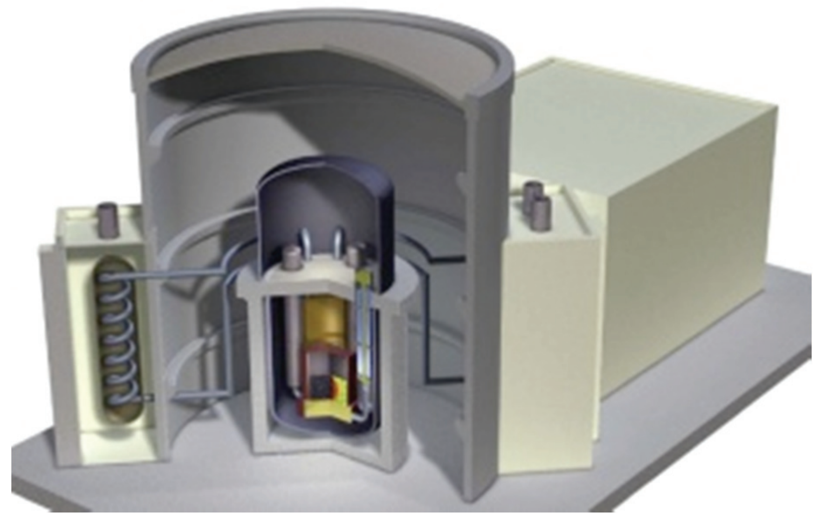
- Small plant with potential for 30 yr lifetime
- Large technology base
- Large company backing concept
- Potential as a “burner” reactor for actinides
- Improved safety



Terra Power – Travelling Wave Reactor



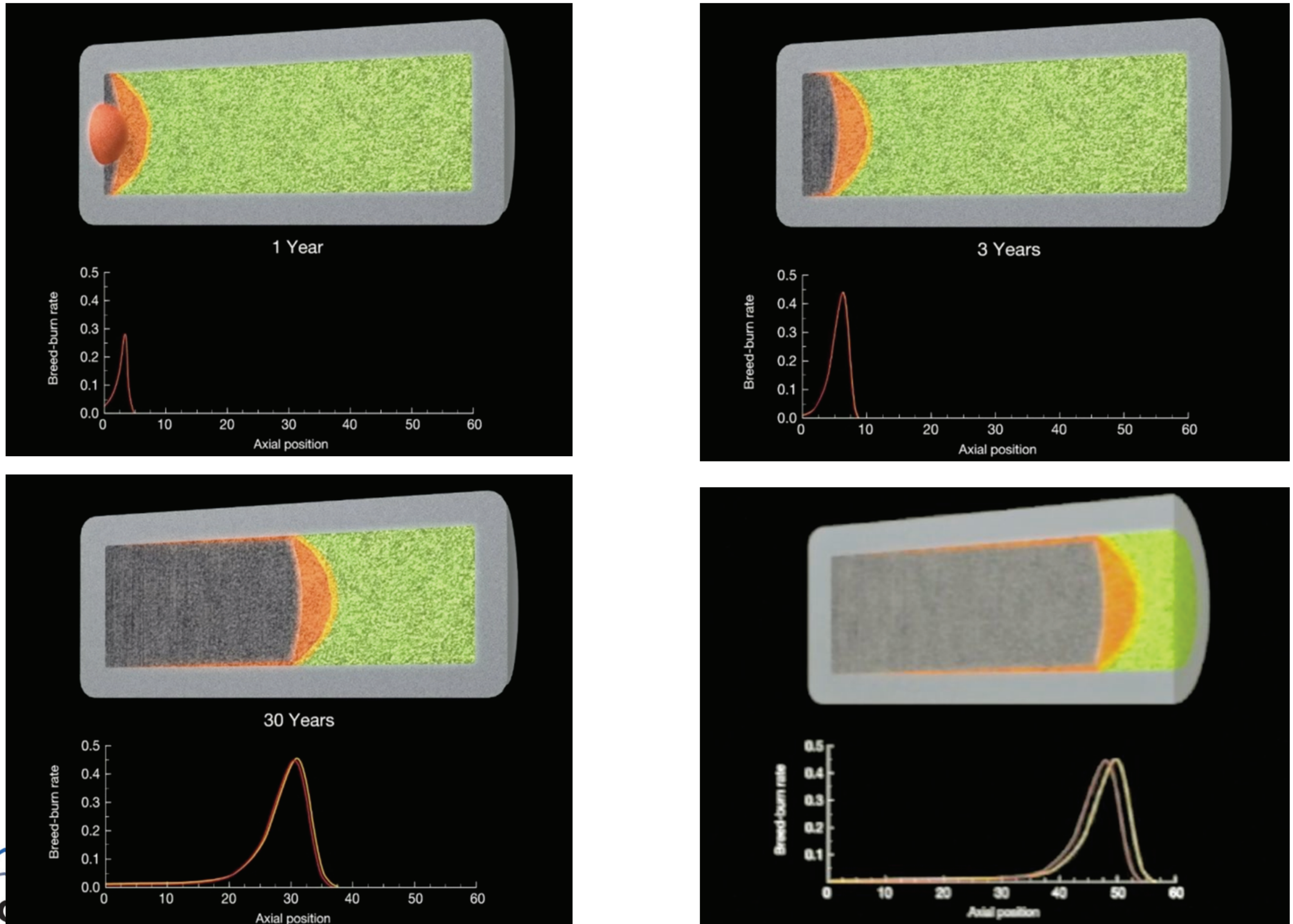
- Most noted for having Bill Gates as one of its funders.
- Potential for really long live reactor (50 to 100 years?)
- Uses depleted uranium as fuel



The Travelling Wave Reactor Concept

- Waves of breeding and burning will propagate through fertile material indefinitely
- Once "ignited,"a steady-state deflagration wave propagates through a U-238 core
  - The wave breeds fissile Pu-239
  - The wave fissions the bred Pu-239 as well as some of the U-238 directly
- *Huge stores of depleted uranium waste a viable fuel sufficient for tens of thousands of years for 10 billion people!*
- Enriched U needed only for reactor start U-233, U-235, or Pu-239
  - Then Transplated Wave
  - Perhaps someday with only an accelerated particle beam

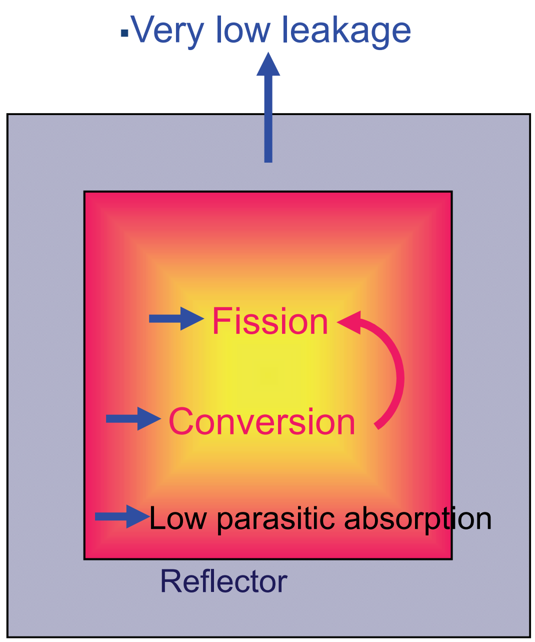
How the Concept Works



General Atomic – EM²

Approach: Create very good neutron economy in small core size

- Fast spectrum
- Very low absorption structural materials (SiC)
- Very high U loading
- Very effective reflector (BeO-graphite)



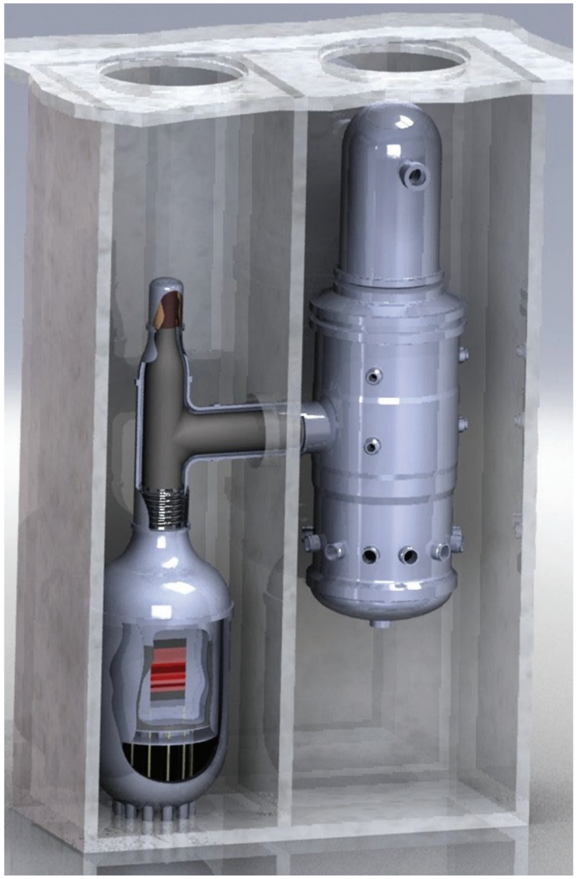
Objective: maximize neutrons going to fission &conversion

Result: 97% of neutrons result in fission or ^{238}U ➔ ^{239}Pu conversion (and higher actinides) at BOL*

- Long core life
- Extract energy from fuels with high FP content
  - Used LWR fuel
  - Recycled EM² fuel

*declines to 82% at EOL

Summary Technical Description of EM^2

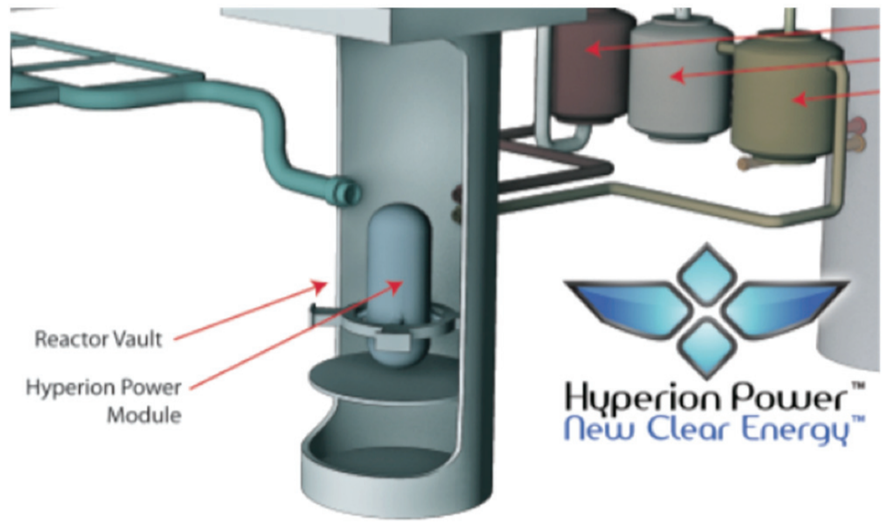


- EM^2 reactor and power conversion system in below grade caisson

- Grid capable: 500 MWt ➔ 240 MWe with gas turbine
- 850°C core outlet temp enables process heat applications, e.g. H_2 production & biofuel
- He-cooled, ceramic fast reactor – converts/fissions U^{238} to Pu^{239} in-situ
- Fuel is spent nuclear fuel (w/o reprocessing) and/or depleted-U,
- No refueling: 30+ year core life @100% duty factor
- Passively safe, underground sited
- Modules can be made in U.S. and shipped by road

Hyperion Power Generation

- To create a revolutionary enterprise that provides community and industrial energy that is environmentally friendly, safe, secure, and affordable
- To design, develop, manufacture, install, and service small nuclear power units in the range of 20 to 50 MWe in multiple market segments worldwide



Hyperion Power Module

1. Transportable

- 1.5 x 2.5 meter unit fits into standard fuel transport container

2. Safety

- All credible accident scenarios resolved within the design
- Underground siting – safe from natural & manmade events
- Lead bismuth (LBE) is non-reactive in air and water, and provides shielding during transport

3. Minimal In-core Components

- Operational reliability is enhanced by the reduction of moving mechanical parts

4. Sealed Core – Safe and Secure

- Factory sealed
- No in-field refueling
- Operates at ambient pressure; no pressure vessel

5. Operational Simplicity

- Operation limited to reactivity adjustments to maintain constant temperature output

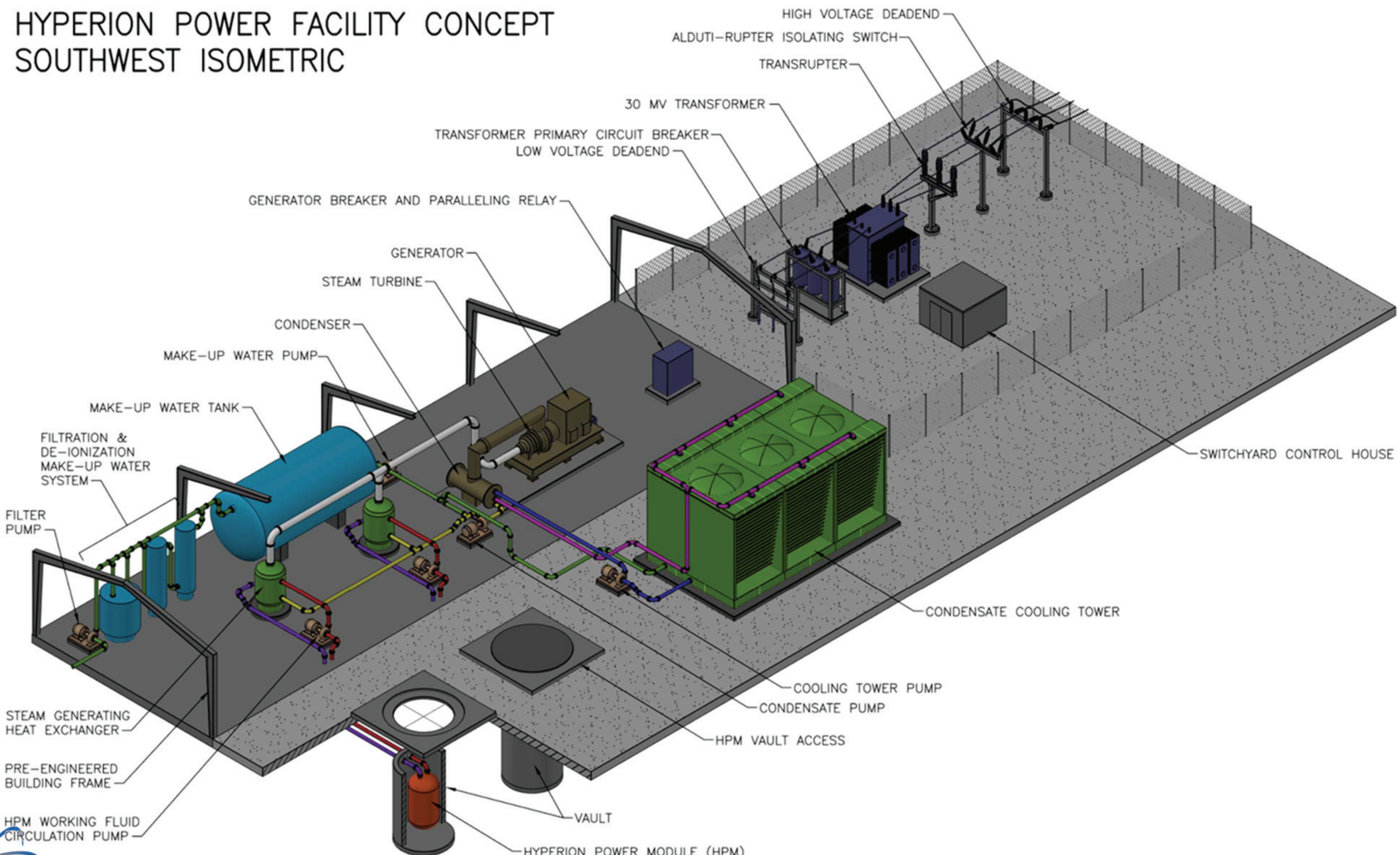
6. Isolated Power Production

- Steam and electric components separated from reactor for maintenance & safety
- Allows existing generation facilities to be retrofitted (HPM replaces heat source)

Features of the HPG Concept

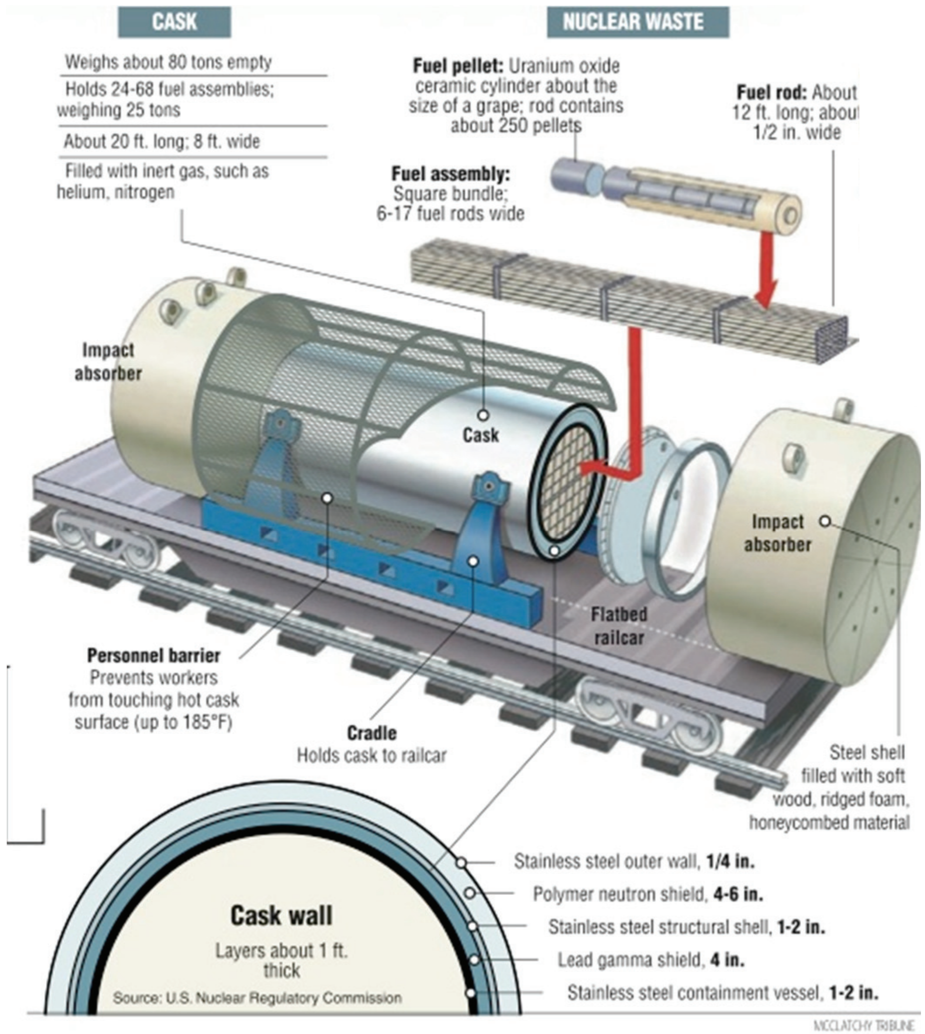
- 70 MWt power to coolant
- 10-year lifetime
- UN fuel at 19.75% enrichment
- HT-9 steel structure (fuel clad thickness = 0.050 cm)
  - Gas plenum height set to limit stress to <1/3 UTS and creep to <1%
  - Includes fabrication tolerances and corrosion allowances
- Lead-bismuth eutectic (LBE) coolant
  - 44.5 w/o Pb, 55.5 w/o Bi
- LBE inside the fuel pin (thermal bond).
  - Gap sized to permit assembly and to preclude FCMI throughout life
- Quartz radial reflector
  - 80% density SiO2
- Shutdown/control B4C rods
  - 80% dense, 80% enriched in B10
- A B4C pellet shutdown mechanism
  - 65% dense, 80% enriched in B10

Hyperion Power Module
Electric Generation Plant Configuration



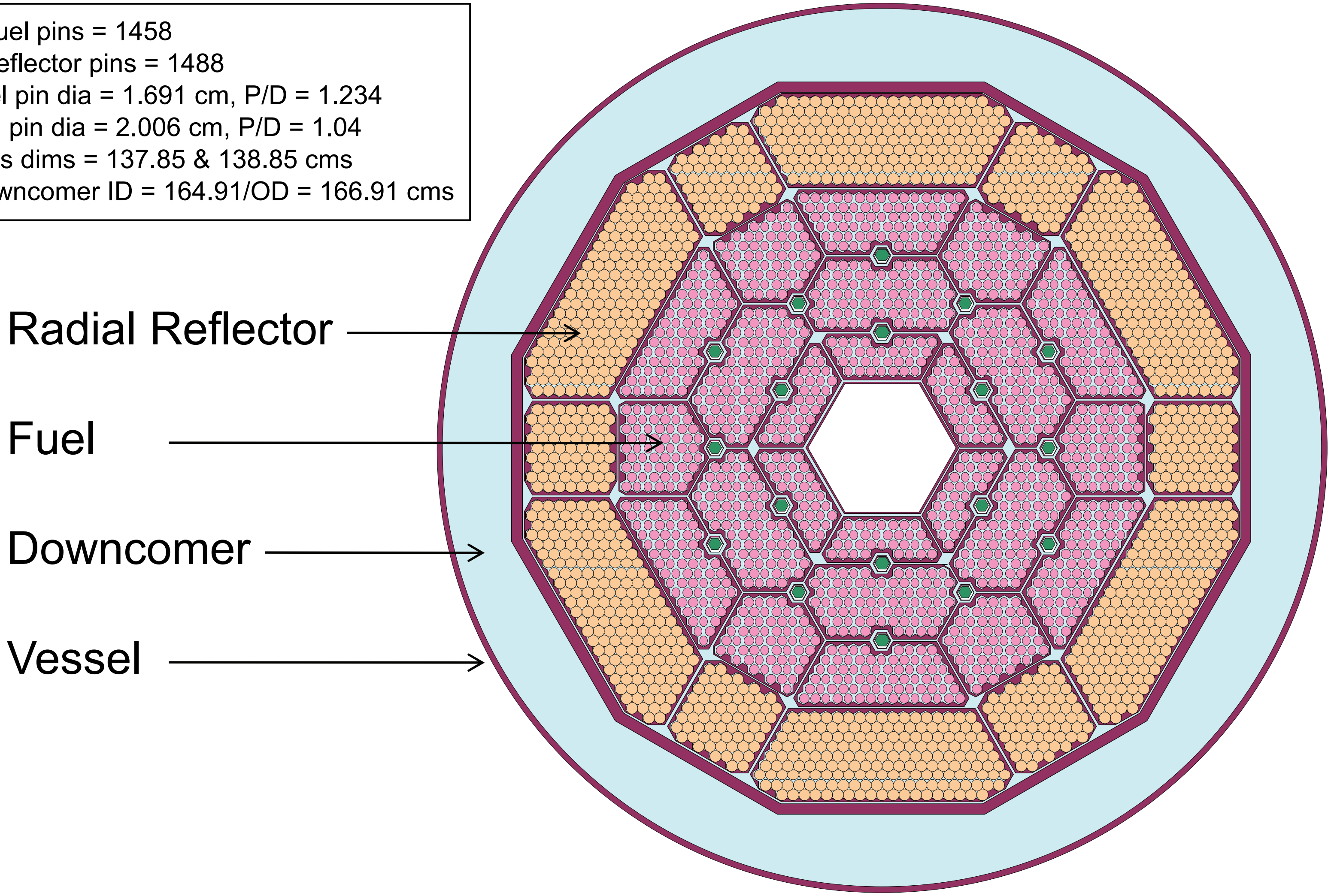
Rail Shipping Cask

- **Vessel and core designed for transport in existing cask envelope**



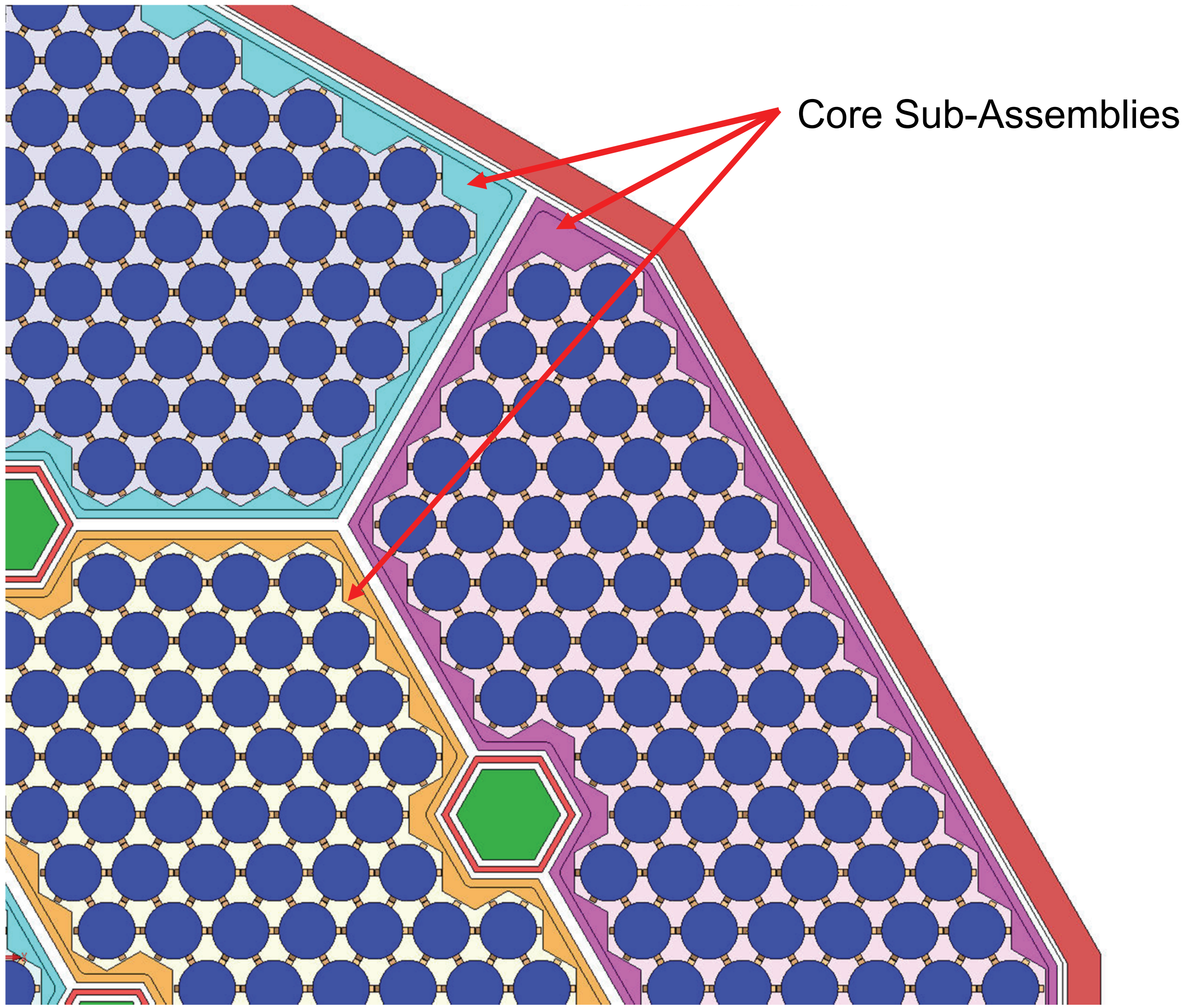
Core Design with Shaped Core Sub-Assembly Structures and Centering Pads

fuel pins = 1458
reflector pins = 1488
fuel pin dia = 1.691 cm, P/D = 1.234
refl pin dia = 2.006 cm, P/D = 1.04
flats dims = 137.85 & 138.85 cms
downcomer ID = 164.91/OD = 166.91 cms

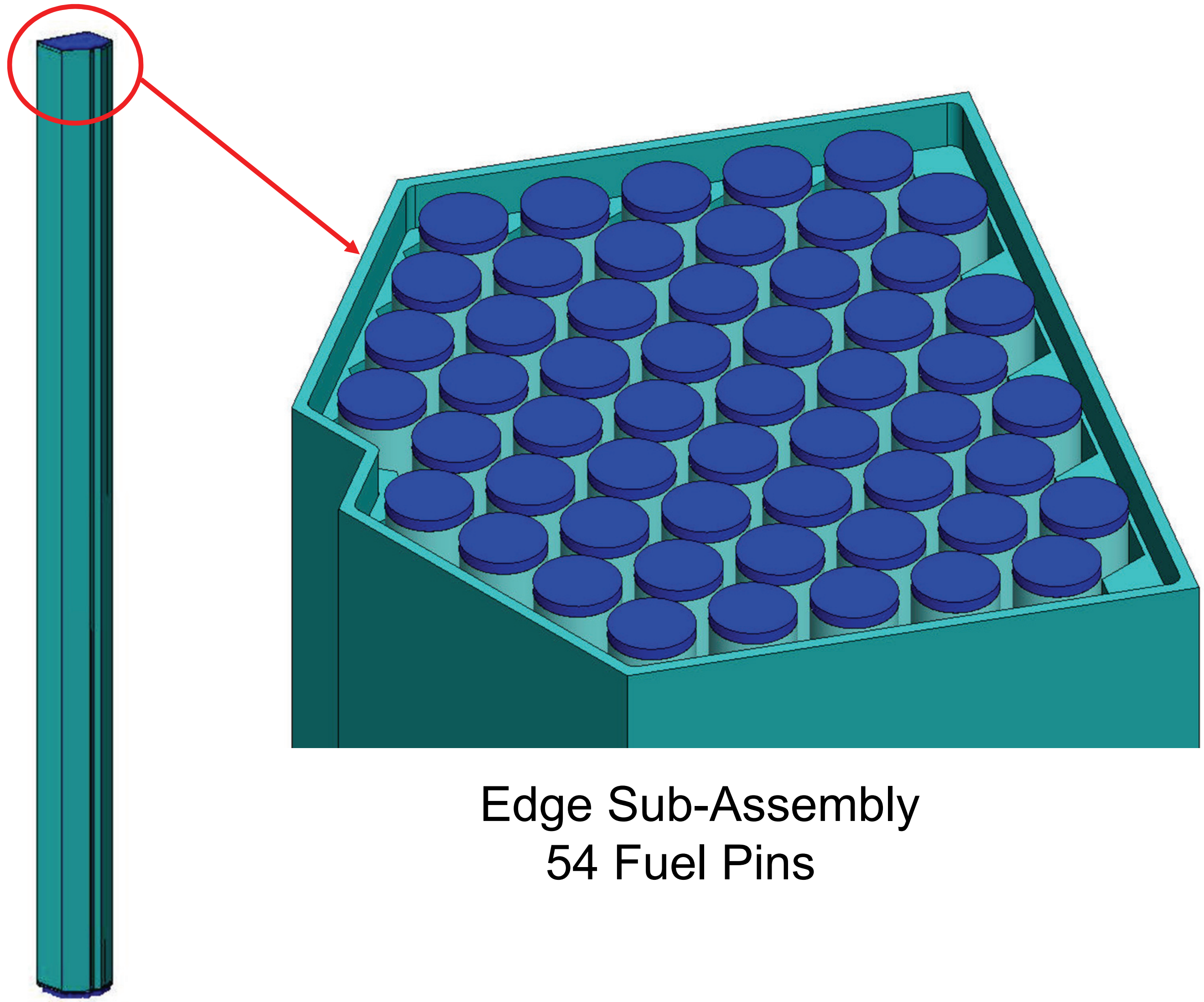


Planview - hyn10h Design

Reactor Core Sub-Assemblies

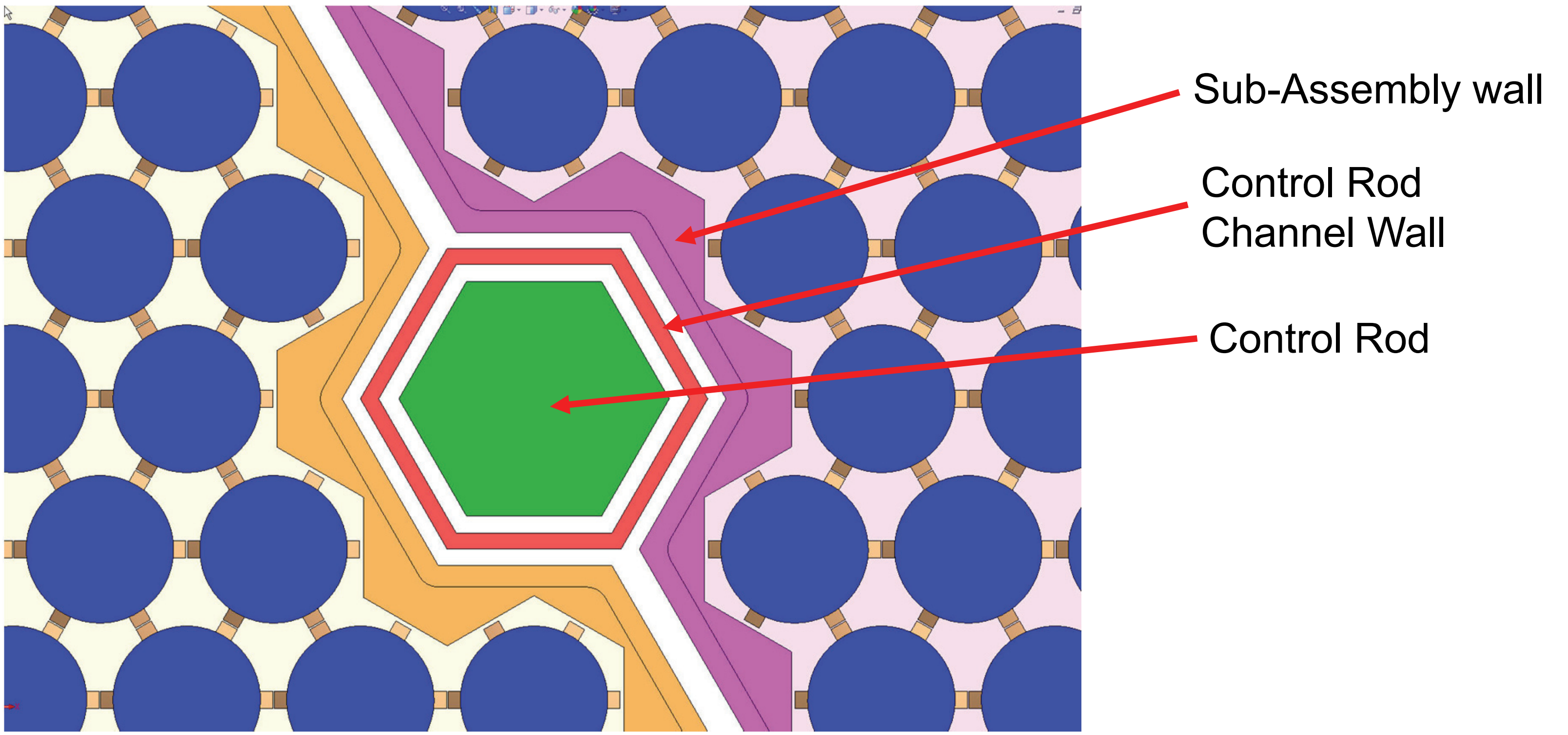


Core Sub-Assembly

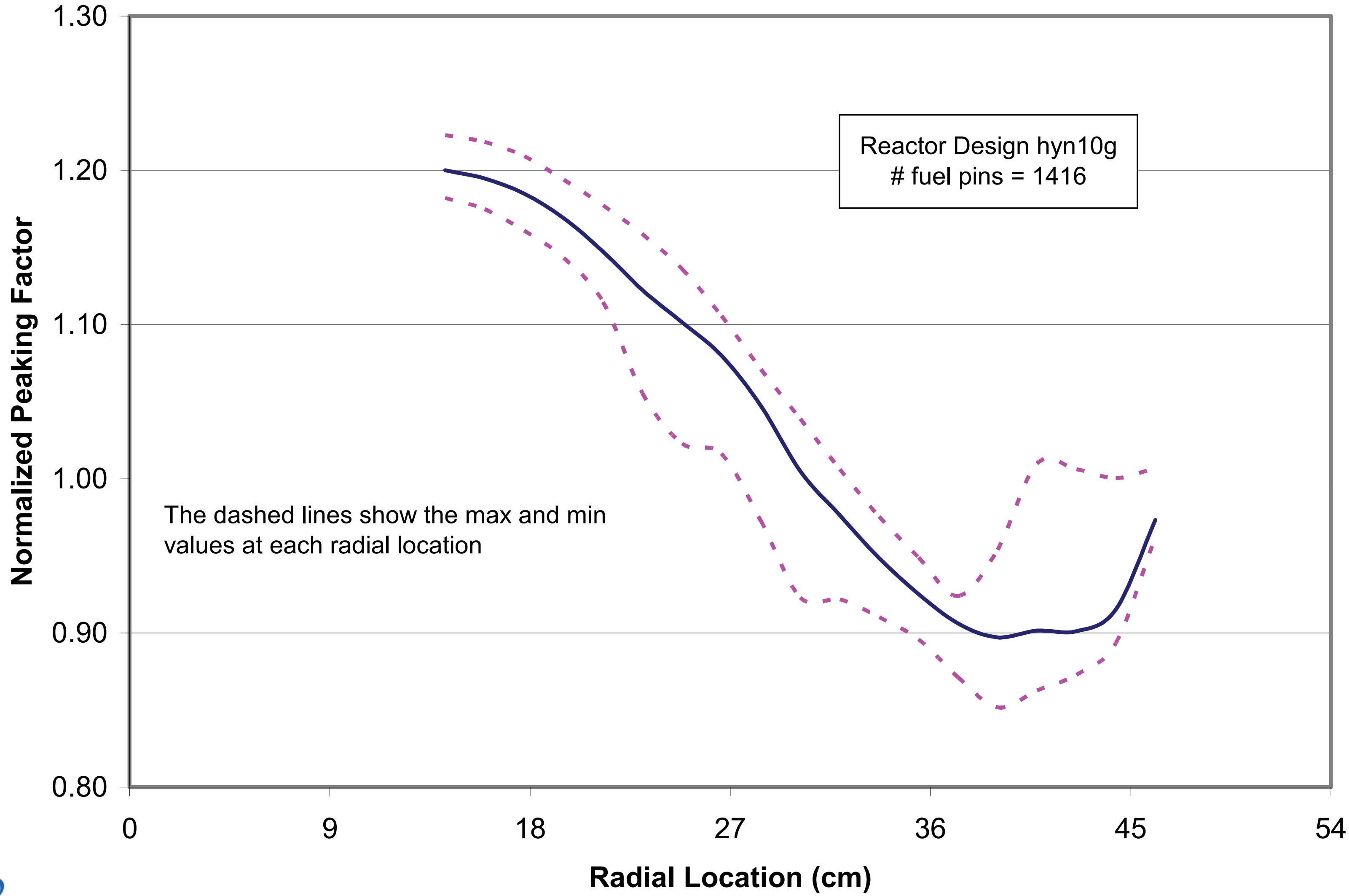


Edge Sub-Assembly
54 Fuel Pins

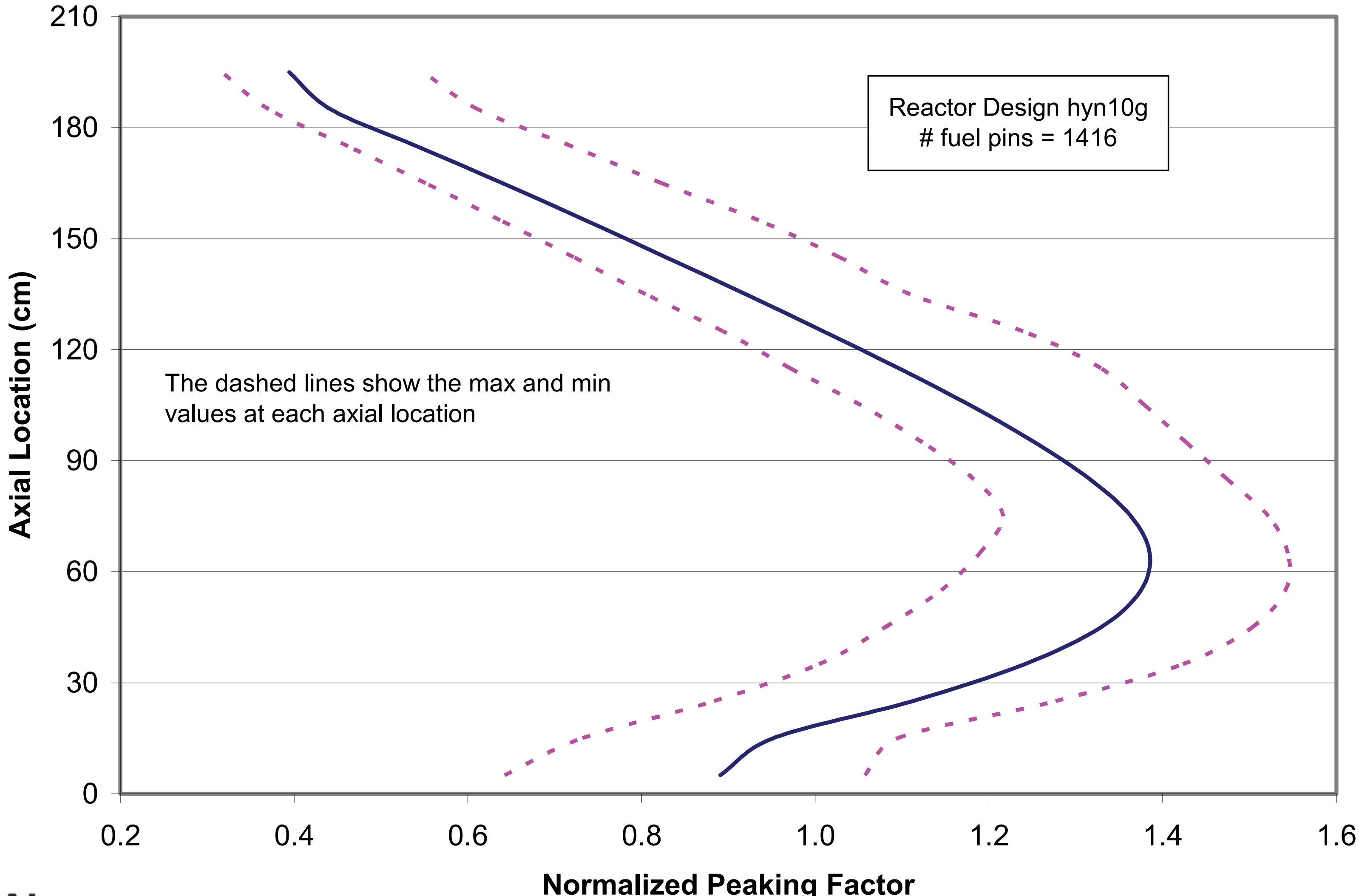
Control Rod Design



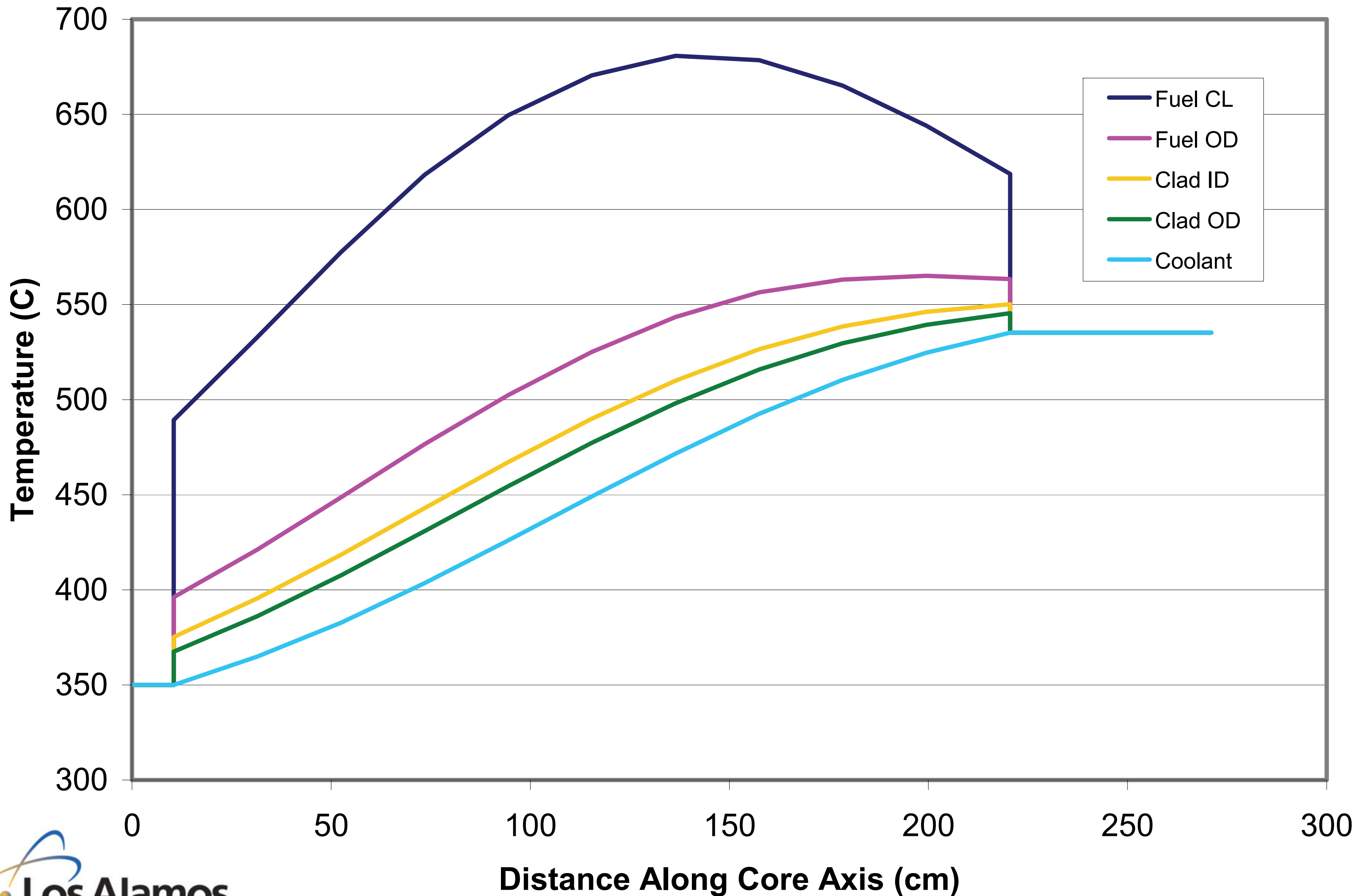
Time-Average Core Radial Power Distribution



Time-Average Core Axial Power Distribution



Peak Power Fuel Pin BOL Temperatures



Other SMRs

- Westinghouse – IRIS, Advance Light Water Reactor (PWR) with passive safety and modular construction
- SNL – Sodium cooled fast reactor concept using super-critical CO_2 cycle for power conversion
- LLNL – SSTAR, UN fuel, LBE cooled fast reactor
- ANL – Sodium cooled fast reactor concept for burning actinides
- ORNL – Molten salt reactor for a range of applications
- LFTR (commercial) – Liquid Fluoride Thorium Reactor

Where I think the DOE is headed

- Would like to get design certification for an SMR
  - Means they have to focus on Light Water Reactor Technology
  - Early money will go to TWO of these concepts
- Would like to help the technology demonstration for other SMRs
  - Lead Bismuth loop, metal fuel, etc. could be aided by DOE
- Would like to develop and demonstrate the licensing processes for a non-LWR SMR
  - Might use Next Generation Nuclear Plant as a guinea pig
  - Industry would like process to be faster than current NRC plans

Where I think industry is headed

- Looking for investment dollars
  - Need to move designs forward
- Looking for customers
  - Especially in the U.S. They would get more attention from the NRC and the government in general if they can identify a U.S. customer
- Looking for a way to get an early plant built
  - Might go overseas if U.S. licensing process looks to be lengthy
  - Many companies have had lots of interest from potential overseas customers