NUSCALE™
Power for all humankind

LO-0619-65988

June 17, 2017

Docket No. PROJ0769

99902043

U.S. Nuclear Regulatory Commission
ATTN: Document Control Desk
One White Flint North
11555 Rockville Pike
Rockville, MD 20852-2738

SUBJECT: NuScale Power, LLC Submittal of Presentation Materials Entitled "ACRS Subcommittee Presentation: NuScale Topical Report – Evaluation Methodology for Stability Analysis of the NuScale Power Module," PM-0619-65962, Revision 0

The purpose of this submittal is to provide presentation materials to the NRC for use during the upcoming Advisory Committee on Reactor Safeguards (ACRS) NuScale Subcommittee Meeting on June 19, 2019. The materials support NuScale's presentation of the "Evaluation Methodology for Stability Analysis of the NuScale Power Module" topical report.

The enclosure to this letter contains the nonproprietary version of the presentation entitled "ACRS Subcommittee Presentation: NuScale Topical Report – Evaluation Methodology for Stability Analysis of the NuScale Power Module."

If you have any questions, please contact Matthew Presson at 541-452-7531 or at mpresson@nuscalepower.com.

Sincerely,

Zackary W. Rad
Director, Regulatory Affairs
NuScale Power, LLC

Distribution: Robert Taylor, NRC, OWFN-7H4
Michael Snodderly, NRC, TWFN-2E26
Samuel Lee, NRC, OWFN-8H12
Gregory Cranston, NRC, OWFN-8H12
Bruce Bavol, NRC, OWFN-8H12

Enclosure: "ACRS Subcommittee Presentation: NuScale Topical Report – Evaluation Methodology for Stability Analysis of the NuScale Power Module," PM-0619-65962, Revision 0

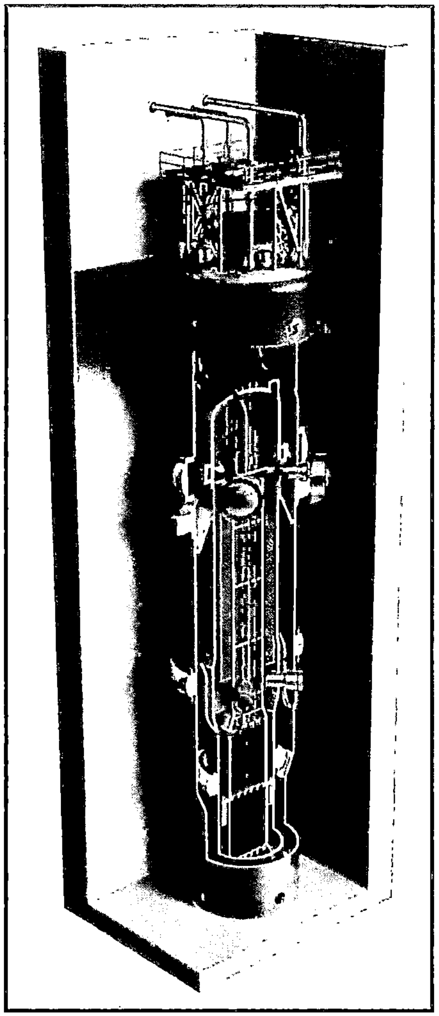
T010
D111
NRO

Enclosure:

"ACRS Subcommittee Presentation: NuScale Topical Report – Evaluation Methodology for Stability Analysis of the NuScale Power Module," PM-0619-65962, Revision 0

NuScale Power, LLC
1100 NE Circle Blvd., Suite 200 Corvallis, Oregon 97330 Office 541.360-0500 Fax 541.207.3928
www.nuscalepower.com

ACRS Subcommittee Presentation



NuScale Topical Report

Evaluation Methodology for Stability Analysis of the NuScale Power Module

June 19, 2019

PM-0619-65962
Revision: 0

NUSCALE
Power for all humankind

Template #: 0000-21727-F01 R5

Presenters

Dr. Yousef Farwila
System Thermal Hydraulics

Ben Bristol
Supervisor, System Thermal Hydraulics

Matthew Presson
Licensing Specialist

Agenda

- Introduction
- Stability Solution Type
- Stability Investigation Description
  - Theoretical
  - Numerical Using New Code PIM
  - Experimental Benchmark
- Procedure and Methodology
- Summary
- Questions and Discussions

The Main Message

- The NuScale Power Module (NPM) design was found to be stable in the entire range of normal operation
- Outside of normal operation, the reactor is destabilized when the riser flow is voided, however
  - Unstable flow oscillation amplitude is limited by nonlinear effects and the critical heat flux ratio actually improves
- The stability threshold is protected by scram upon loss of riser inlet subcooling
  - Conceptually equivalent to a “region exclusion” not a “detect and suppress” solution type
  - No action required to implement a stability solution hardware
- These conclusions are based on extensive first principles, experimental, and computational studies.

Stability Evaluation

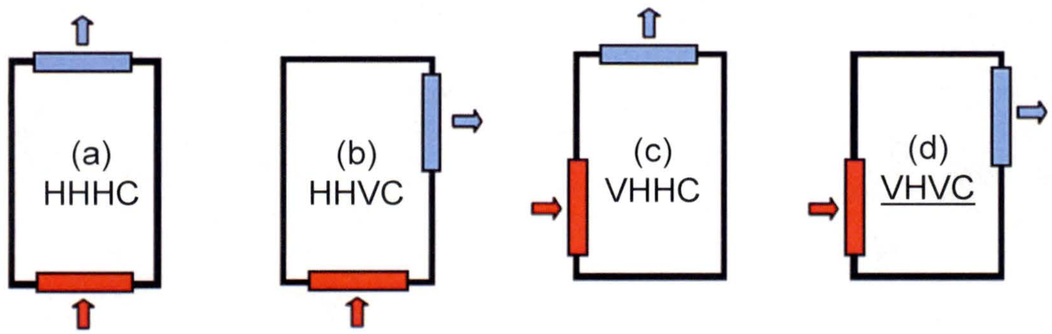
- Natural circulation instabilities were reported
  - See for example D.S. Pilkhwal et al., "Analysis of the unstable behaviour of a single-phase natural circulation loop with one-dimensional and computational fluid-dynamic models," Annals of Nuclear Energy 34 (2007) 339–355.

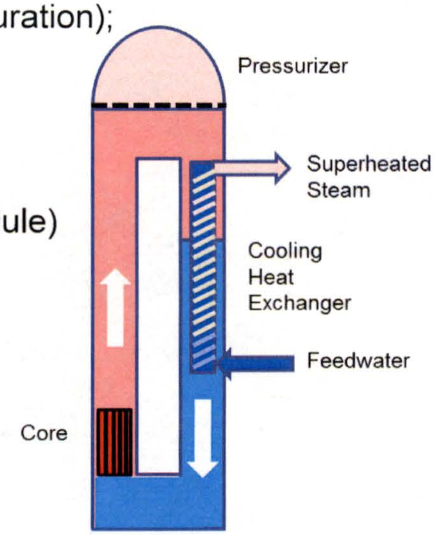
    a) HHHC: horizontal heater and horizontal cooler (the only unstable configuration);

    b) HHVC: horizontal heater and vertical cooler;

    c) VHHC: vertical heater and horizontal cooler;

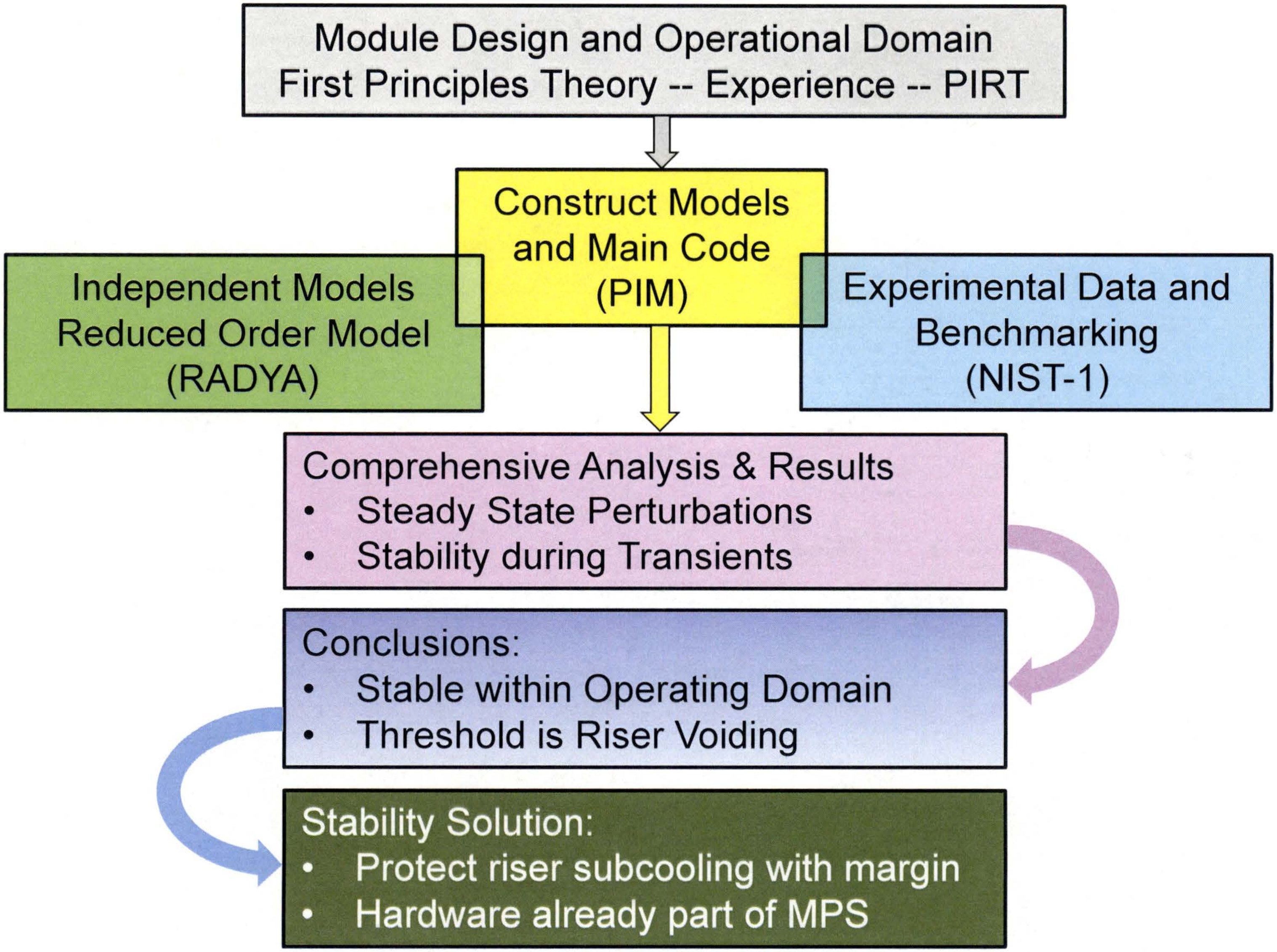
    d) <u>VHVC</u>: vertical heater and vertical cooler (qualitatively like NuScale module)





- Investigation of the NuScale module stability commenced to demonstrate stability, identify threshold conditions, and license stability protection methodology

Stability Investigation Elements



Theoretical Investigation

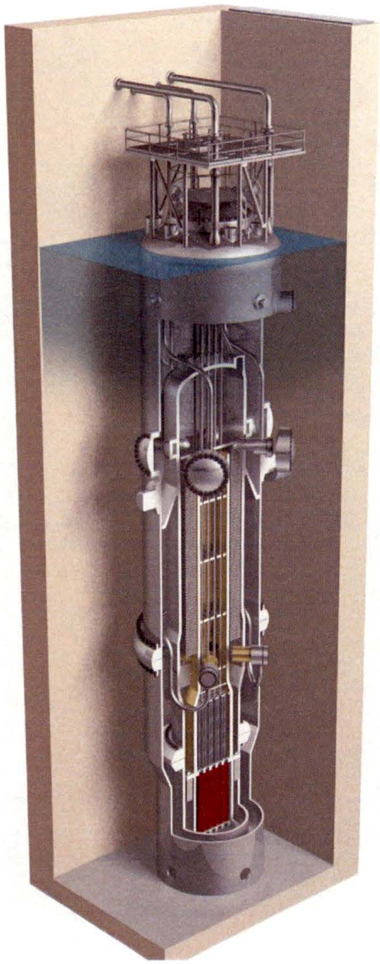
- Kick off with an expert committee to generate a first PIRT
- Scoping review of thermalhydraulic instability modes and contrasting with the NPM design features
- Identification of the possible instability mechanism
- Analysis from first principles
  - Riser-only mode (separate from cold leg)
  - Stability trend with power using a simple SG model
  - Inform design of stability experiments
- All medium ranked phenomena treated as highly ranked

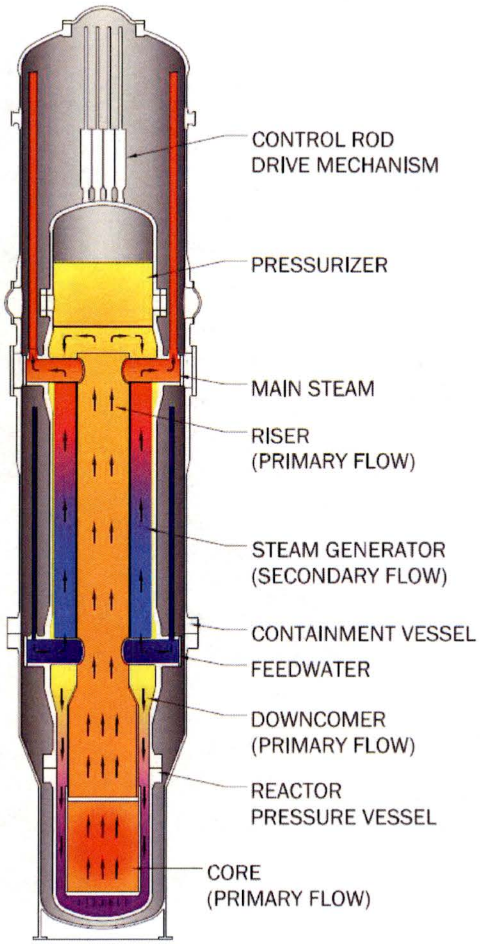
Theoretical and First Principles

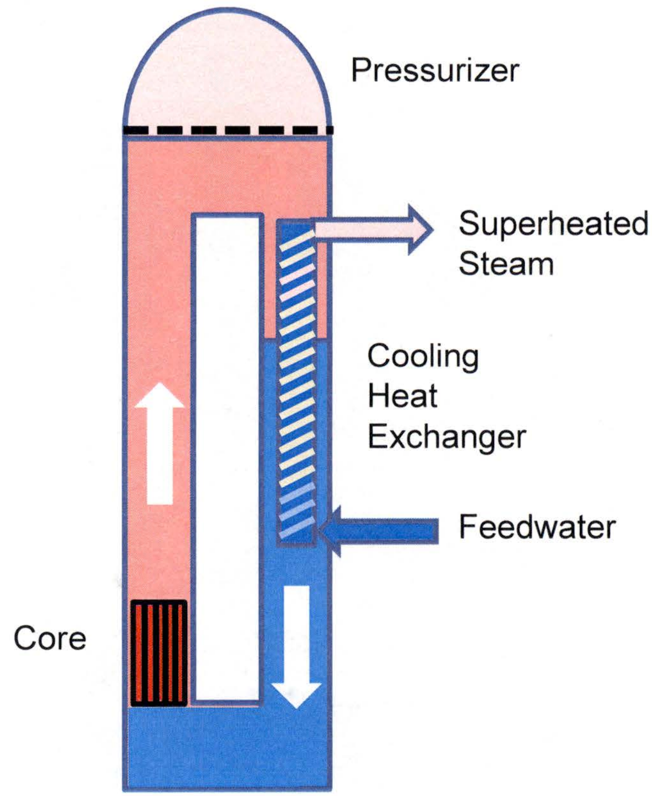
- A system with feedback processes may undergo oscillatory instability if the feedback is:
  - Negative (positive feedback is unconditionally unstable)
  - Delayed
  - Sufficiently strong
- NuScale natural circulation mode is examined
  - Feedback is negative. A perturbation increasing core flow decreases exit temperature thus decreases riser density head
  - Feedback is delayed. Transport delay for core exit condition to fill the riser and reach maximum density head effect.
  - Feedback strength is related to liquid thermal expansion and possibility of phase change, riser length, SG characteristics, reactivity feedback… Requires detailed modeling

Main Stability Analysis Tool: PIM

- Transient 1-D 2-phase non-equilibrium primary loop flow







Model Equations of the PIM code

- Thermalhydraulic conservation equations
  - Liquid and vapor mass balance

$$\frac{dM_{l,n}}{dt} = \dot{m}_{l,n-1} - \dot{m}_{l,n} - \Gamma_n$$

$$\frac{dM_{g,n}}{dt} = \dot{m}_{g,n-1} - \dot{m}_{g,n} + \Gamma_n$$

  - Mixture momentum conservation with drift flux (integrated momentum)

$$\frac{dI}{dt} = \Delta P_{grav} - \Delta P_{friction} - \Delta P_{local} + \Delta P_{resid}$$

  - Energy conservation (assume saturated vapor)

$$\frac{d}{dt}\left(M_{l,n} h_{l,n}\right) = \dot{m}_{l,n-1} h_{l,n-1} - \dot{m}_{l,n} h_{l,n} - \Gamma_n h_{fg} + \dot{Q}_n$$

t	time
M_l	liquid mass
M_g	vapor mass
$\dot{m}_l$	liquid mass flow rate
$\dot{m}_g$	vapor mass flow rate
Γ	rate of evaporation
I	integrated momentum
ΔP_{grav}	gravitational press. drop
$\Delta P_{friction}$	friction pressure drop
ΔP_{local}	local pressure drop
ΔP_{resid}	residual pressure drop
h_l	liquid enthalpy
h_{fg}	latent heat
$\dot{Q}$	power
n	control volume index
$n-1$	upstream index

Model Equations of the PIM code

- Point Nuclear Kinetics

$$\Lambda \frac{d\Phi}{dt} = \beta(\rho - 1)\Phi + \lambda C$$

$$\frac{dC}{dt} = \beta\Phi - \lambda C$$

C	Concentration of the delayed neutron precursors
λ	Decay constant of the delayed neutron precursors
Φ	Neutron flux amplitude
β	Delayed neutron fraction
Λ	Prompt neutron lifetime
ρ	Reactivity

  - Thermalhydraulic model provides reactivity input
    - Moderator density reactivity feedback model (equivalent to moderator temperature reactivity under single-phase flow)
    - Doppler fuel temperature reactivity feedback
  - Heat source from neutron kinetics feeds back to thermalhydraulics
    - Energy deposited in fuel pellets (proportional to neutron flux)
    - Fraction of fission energy deposited directly in coolant
    - Decay heat: input by the user as fraction of initial power

Model Equations of the PIM code

- Heat conduction in fuel rods
  - Pellet conductivity is function of temperature and burnup
  - Driven by energy deposited in fuel pellets
  - Heat flux at outer rod surface as power source to coolant
  - Pellet temperature needed for Doppler reactivity
- Heat transfer models for heat sink (steam generator)
  - Secondary side flow is driven by user-provided inlet forcing function
  - Secondary flow is subcooled, 2-phase equilibrium, and superheated
  - Primary flow parameters calculated from transient conservation equations
  - Heat transfer between primary and secondary flow
    - Heat transfer correlations
    - Transient heat conduction in tube walls

Model Equations of the PIM code

- Closing Relations and Correlations
  - Frictional pressure drop (single- and two-phase friction and local losses)
  - Drift flux parameters
  - Non-equilibrium evaporation and condensation model
  - Thermodynamic properties for water
  - Physical material properties (pellets, cladding, SG tubes)
  - Pellet-clad gap conductance
  - Reactivity coefficients as functions of exposure and moderator density
- What is not modeled
  - Pressurizer; pressure is input provided constant or forcing function
  - Heat transfer through riser wall, adiabatic riser is default option
  - Heat capacity of structures; only ambient heat losses through vessel

PIM Results of Perturbing SS

- Purpose is to calculate stability parameters of decay ratio and period at different conditions of power and exposure
  - Following a user-applied small perturbation flow will oscillate
  - Oscillations will grow with time if system is unstable
  - Oscillations will decay eventually returning to the pre-perturbation state if the system is stable
- Stability parameters, decay ratio and period, are extracted from the transient output. Observations:
  - Unconditional stability in the entire operational range
  - DR decreases with power and exposure
  - Period also decreases with power
  - Observations agree with the independent Reduced Order Model

PIM Application Methodology

- For perturbations of steady state to get DR
  - Vary power within 5-100% of rated
  - BOC and EOC, and any point in between if warranted
  - Conservative assumptions for MTC and decay heat fraction
- For a depressurization transient (scram not credited)
  - Verify that unstable oscillations limit cycle without CHFR decrease
- Stability conclusion is generic, but confirmation is needed
  - For plant upgrades such as power uprates
  - Plant operation changes such as operating temperatures and maximum boron concentration
  - Changes in fuel design that would change natural circulation flow

Long Term Stability Solution

- Region Exclusion for NuScale
  - Unstable region defined by a single parameter (core exit subcooling)
  - Monitor and protect margin to riser exit subcooling (with temperature margin below saturation point at pressurizer pressure)
  - Operator alarm when subcooling margin is approached
  - Riser exit subcooling will be controlled by the reactor protection system as part of normal operating limits – not only for preventing instabilities
  - Generic solution: there are no fuel or cycle design elements

Summary and Conclusions

- Stability of the NuScale module was evaluated using a dedicated code (PIM) and supported by first principles analysis and experimental data benchmarking
- The module was found unconditionally stable within normal operation domain using conservative criterion
- Stability boundary identified as associated with riser voiding (loss of riser inlet subcooling)
- Stability protection methodology protects riser inlet subcooling with a margin to define the exclusion region enforced by the module protection system with scram

Portland Office
6650 SW Redwood Lane,
Suite 210
Portland, OR 97224
971.371.1592

Corvallis Office
1100 NE Circle Blvd., Suite 200
Corvallis, OR 97330
541.360.0500

Rockville Office
11333 Woodglen Ave., Suite 205
Rockville, MD 20852
301.770.0472

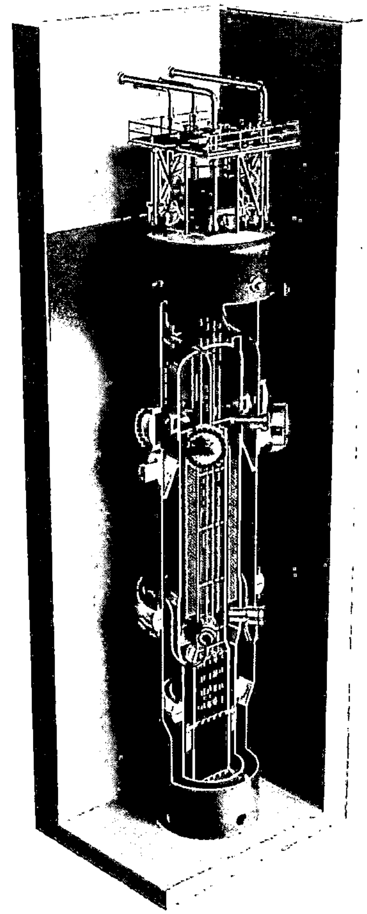
Charlotte Office
2815 Coliseum Centre Drive,
Suite 230
Charlotte, NC 28217
980.349.4804

Richland Office
1933 Jadwin Ave., Suite 130
Richland, WA 99354
541.360.0500

Arlington Office
2300 Clarendon Blvd., Suite 1110
Arlington, VA 22201

London Office
1st Floor Portland House
Bressenden Place
London SW1E 5BH
United Kingdom
+44 (0) 2079 321700

http://www.nuscalepower.com
Twitter: @NuScale_Power



NUSCALE™
Power for all humankind