Small Modular Reactors: A Call for Action

Overview of Five SMR Designs

by Dr. Regis A. Matzie
Executive Consultant

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Current Water-Cooled SMR Designs

Reactor	Type	Power, MWe	Country	Vendor
CAP-100	PWR	100	China	CNNC
CAREM	PWR	27-100	Argentina	CNEA
FLEXBLUE	PWR	160	France	DCNS
KLT-40S	PWR	35	Russia	OKBM
mPower	PWR	180	USA	B&W
NuScale	PWR	50	USA	NuScale Power
SMART	PWR	100	Korea	KAERI
SMR-160	PWR	160	USA	Holtec
W-SMR	PWR	225	USA	Westinghouse

- *Today, there are over 40 SMR designs in total in various stages of development worldwide*
- *Development is advanced for 17 of these: 10 light water reactors, 3 high temperature reactors, 4 fast reactors*

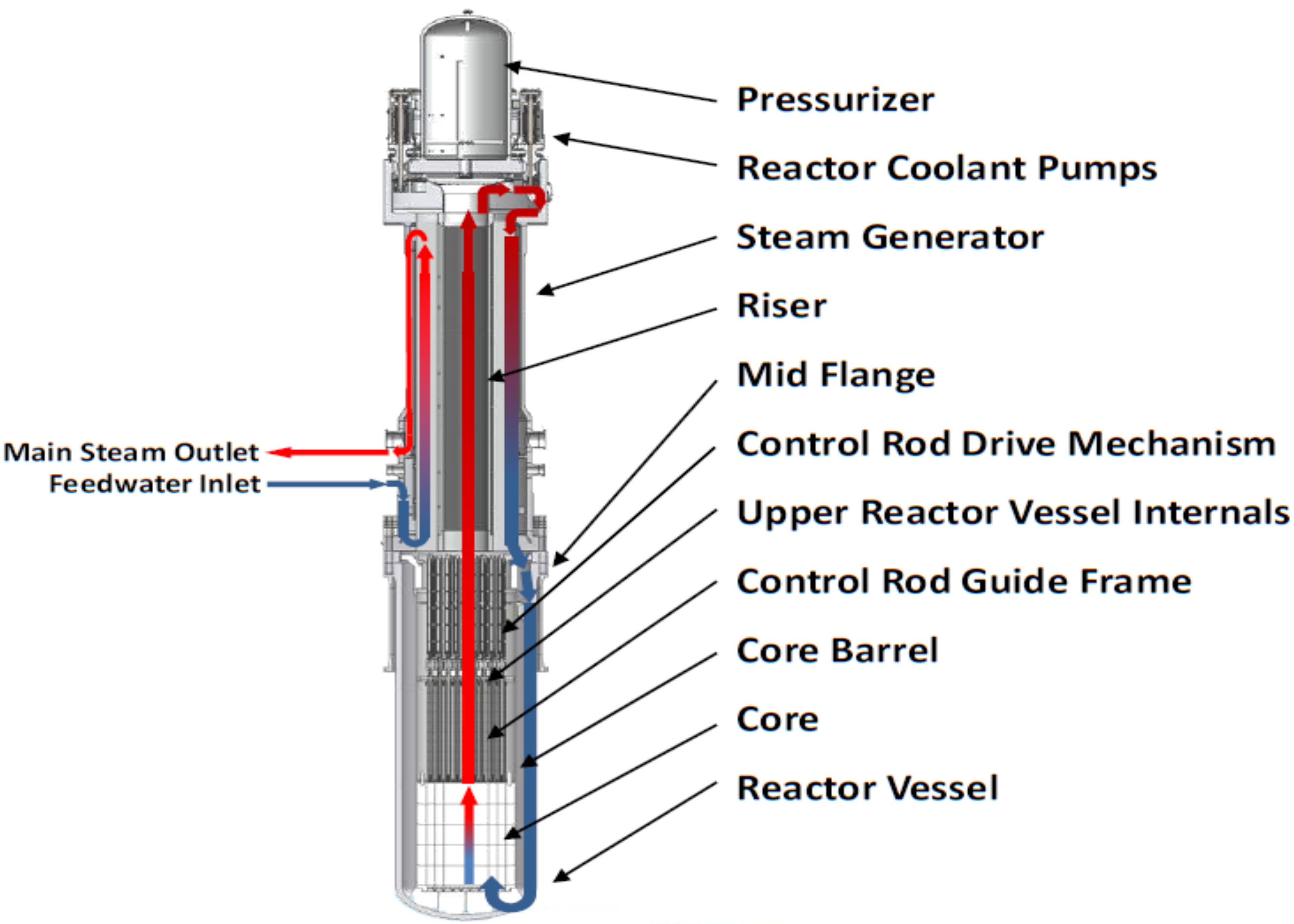
Selected SMR Design Parameters

Reactor	# Fuel Assemblies	# Control Rod Drive Mechanisms	RCS Circulation	Chemical Shim	Fuel Cycle Length, yrs
mPower	69	69	Forced	No	4
NuScale	37	16	Natural	Yes	2
SMART	57	25	Forced	Yes	3
SMR-160	37	37	Natural	No	4
W-SMR	89	37	Forced	Yes	2

- *All designs use standard 17x17 PWR fuel*
- *All designs have 60-year design life*

Generation mPower SMR

mPower Primary System



- *Internal control rod drive mechanisms (CRDM)*
- *Canned rotor pumps (8 total)*
- *Once-through steam generators*
- *Lowest penetration is 23 ft. above top of active fuel*
- *Full core replacement used to achieve 4 year operating cycle*
- *Shortened fuel assembly (compared to commercial fuel)*
- *Axial graded burnable poison rods (Gd_2O_3 mixed with UO_2)*
- *Control rods are aluminum carbide and B_4C*

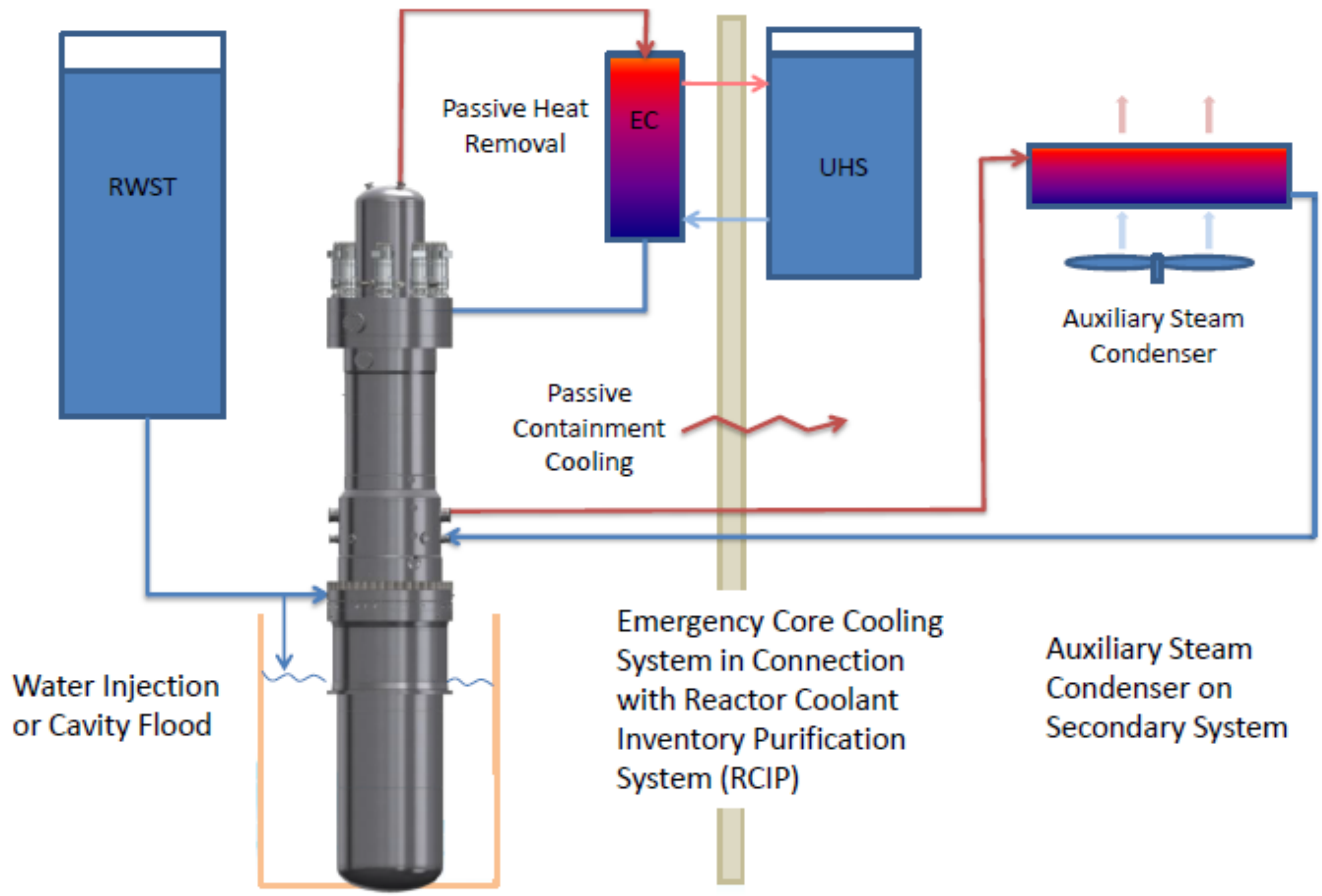
mPower
Enhanced Physical Protection

- **Low profile architecture (improved seismic response)**
- **Underground containment (more robust against external events)**
- **Enhanced security (from external threats)**
- **Underground spent fuel pool (greater integrity)**

"Twin-pack" Configuration

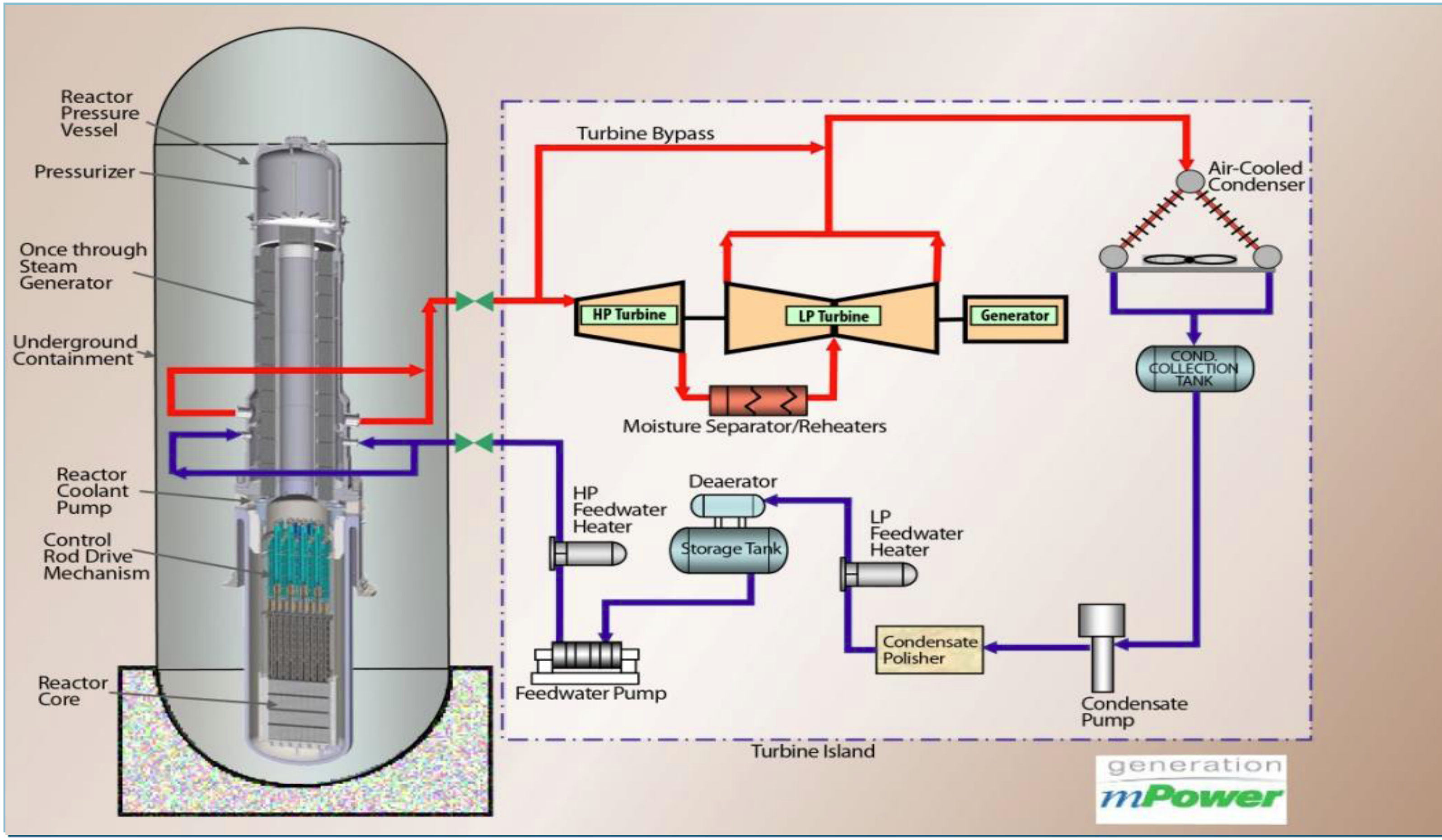
- *All safety systems underground – water tight and isolated from the environment*
- *No shared safety systems between units*
- *Spent fuel pool has 30 days coping time*
- *20-year storage capacity*

mPower Safety Systems



- *Passive core cooling (AC power not required for safety function)*
- *Emergency core cooling by gravity feed*
- *Core remains covered during all postulated accidents*
- *14 day coping time under station blackout*
- *72 hour safety-related control/monitoring batteries*
- *30 day+ boil off for Spent Fuel Pool*

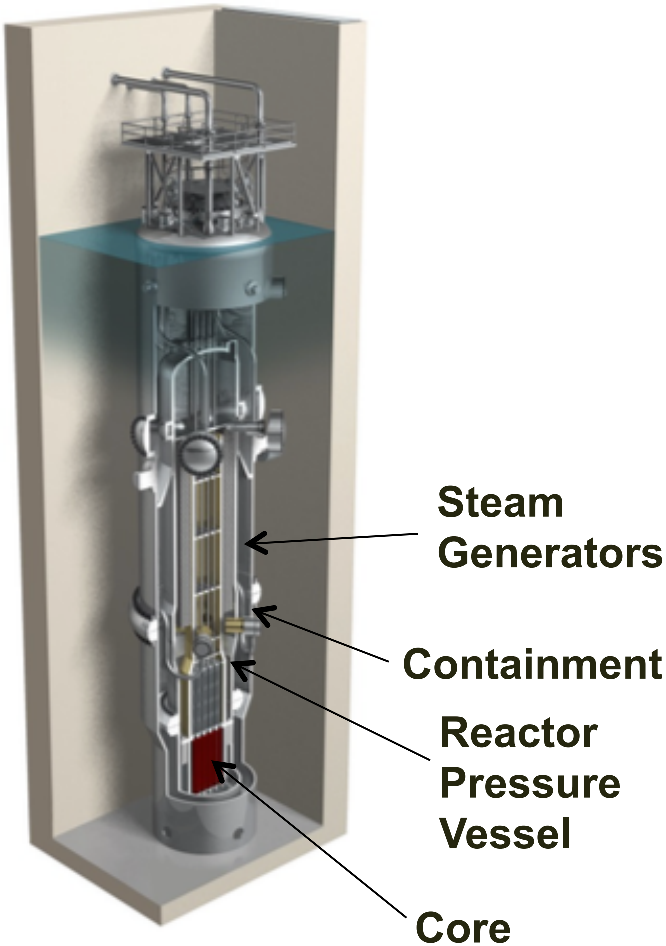
mPower Balance Of Plant

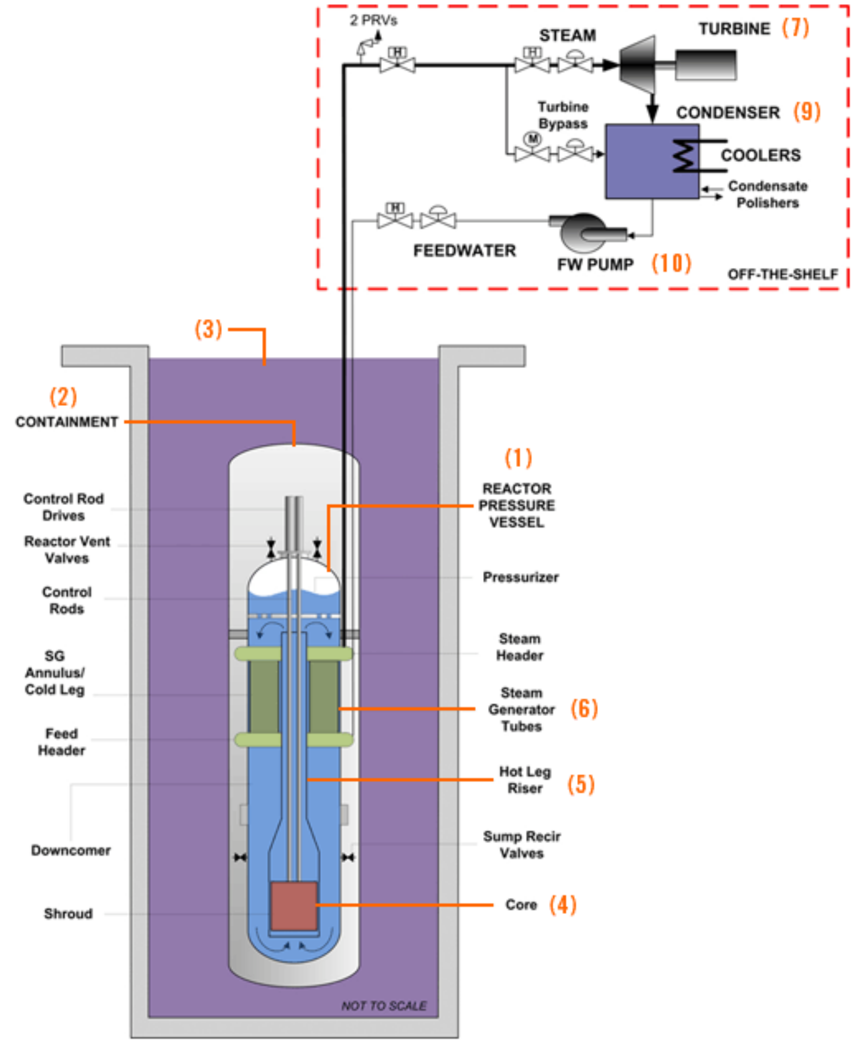


- *Conventional steam cycle components*
- *Air-cooled condenser possible (at expense of efficiency and higher capital cost)*
- *One-to-one reactor to turbine-generator alignment*
- *50 degree superheat in secondary*

NuScale Power SMR

NuScale Primary System

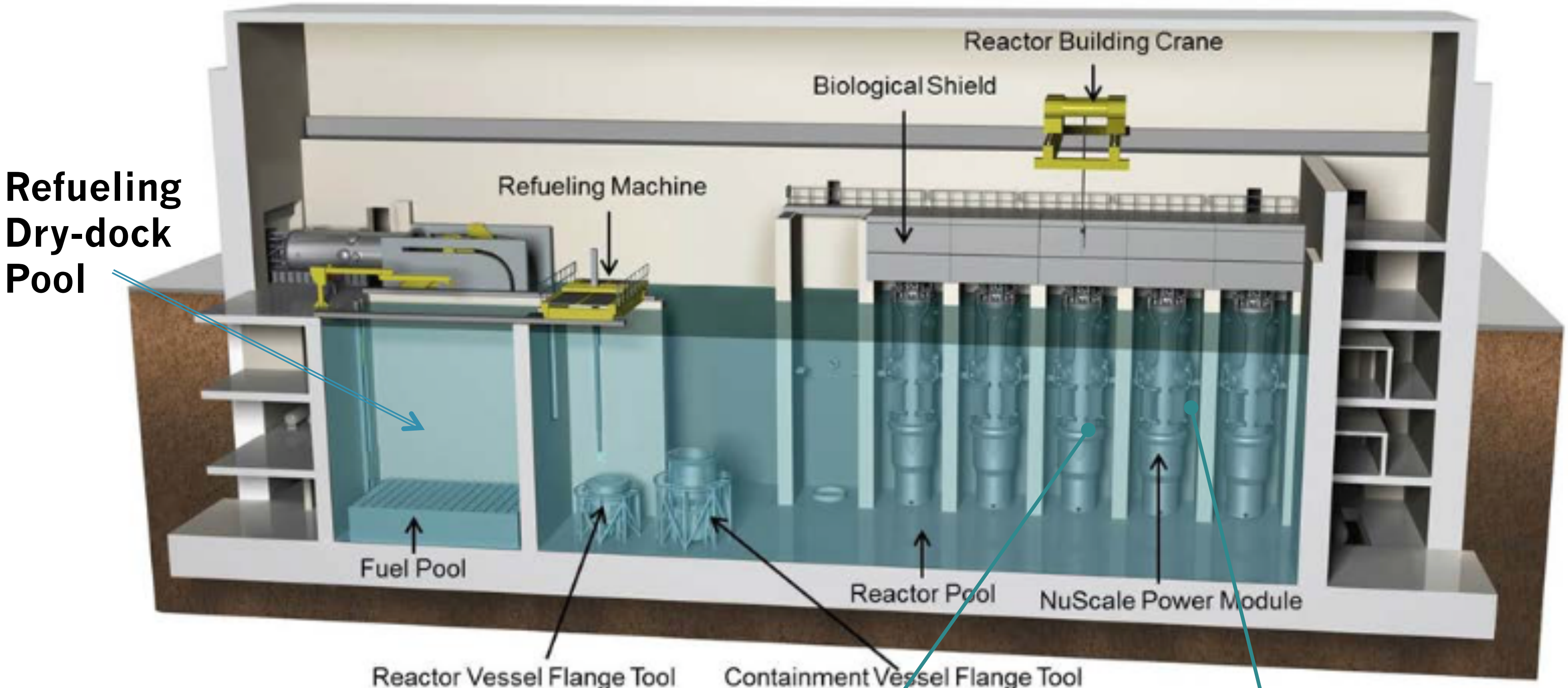




- *Fuel is 17x17 about 6 feet in height; design uses full core replacement with 2-year cycle at 4.95% U235 enrichment*
- *Standard external magnetic jack CRDMs*
- *Reactor Pressure Vessel is ~61 feet in height and ~9 feet in diameter*
- *Containment is 76 feet in height and 15 feet in diameter*
- *Steam Generators are 2 once-through helical-coil design with superheat*
- *CVCS used to add heat to the reactor coolant during startup*

NuScale Modular Design

12-module, 570 MWe NuScale Plant



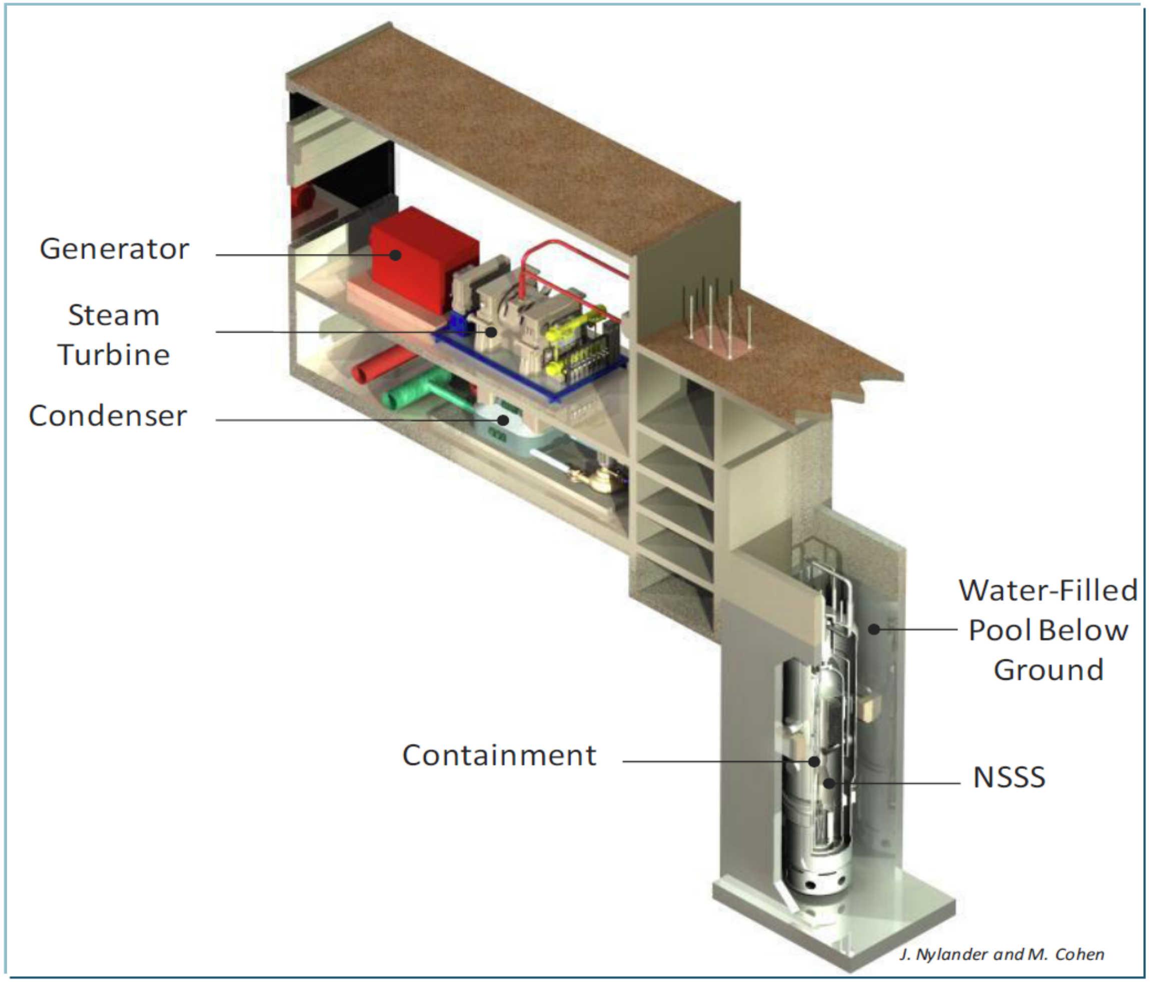
Reactor and containment are submerged in underground steel-lined concrete pool with sufficient water to support unlimited coping period.

Any hydrogen released is trapped in containment vessel with little to no oxygen available to create a combustible mixture.

- *Multiple modules co-located at site to create mid-to-large-size plant*
- *Common pool for 12 reactor modules*
- *Each module installed in its own seismically isolated bay*
- *Six reactor modules planned for initial installation*
- *Each module refueled underwater while others continue to operate; target refueling time is 10 days*
- *Roof of structure is 77 feet above grade*
- *Top of concrete floor is 76 feet below grade*

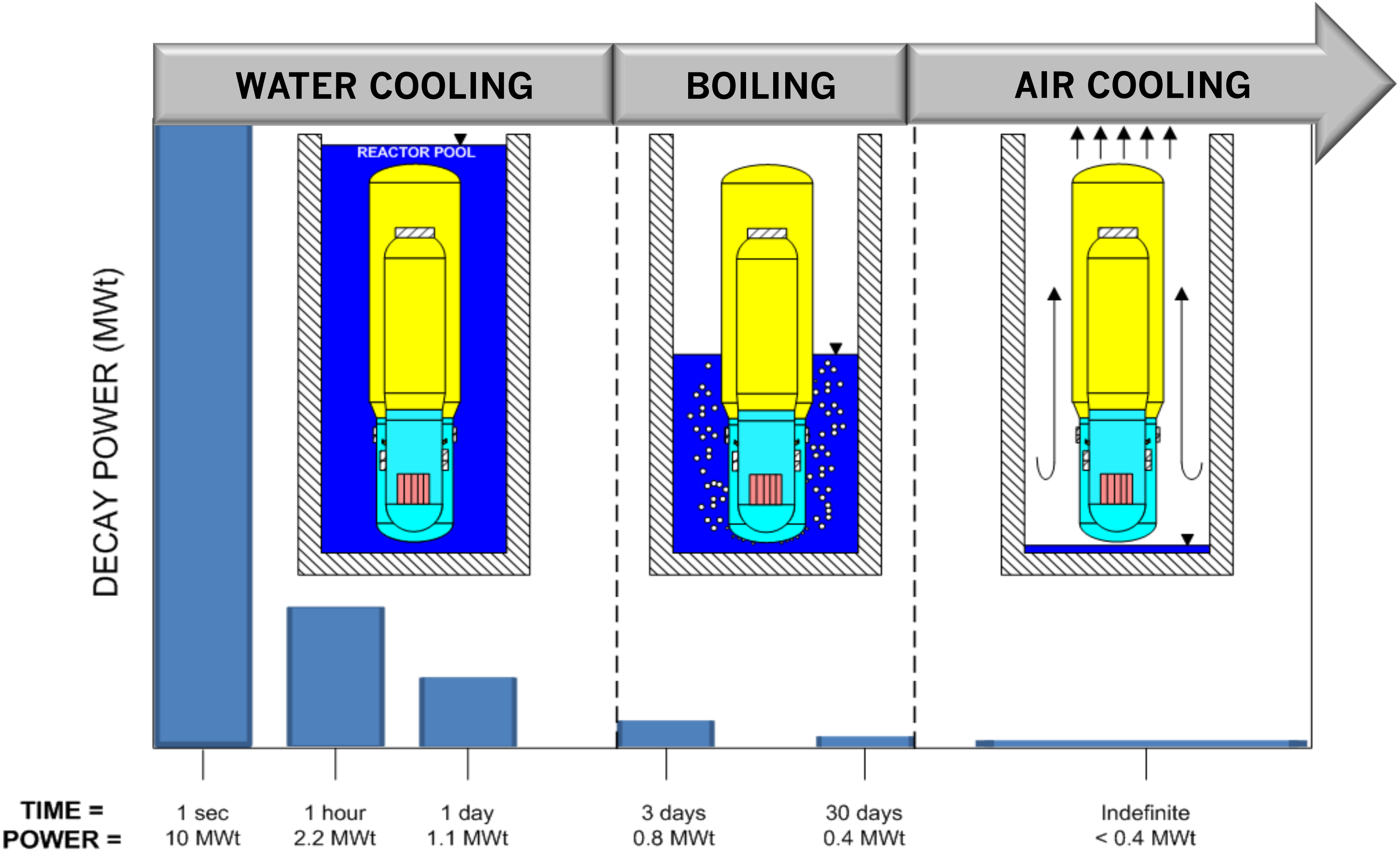
NuScale Balance Of Plant Features

Each module has an independent BOP



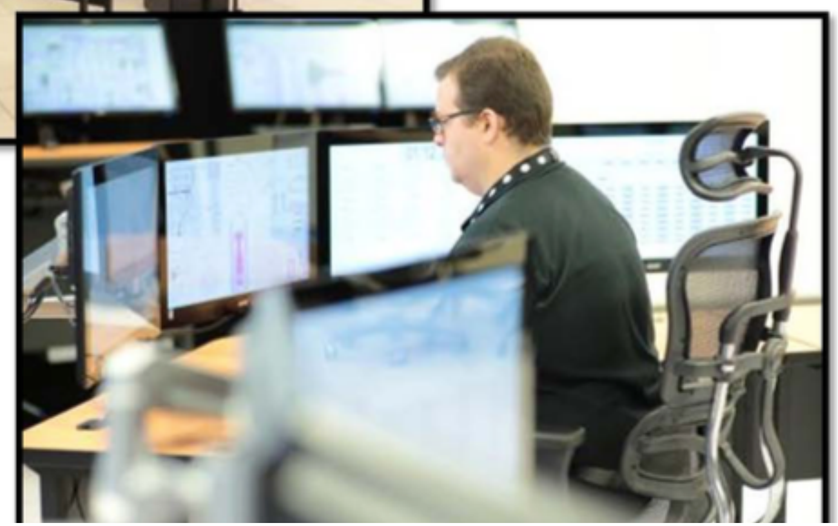
- *The turbine-generator set is skid-mounted*
- *One BOP for each module and at 50 Mwe each*

NuScale Long-term Containment Cooling



- *NuScale module is 160 MWth*
- *At 1 second, the decay heat is approximately 7% of rated power*

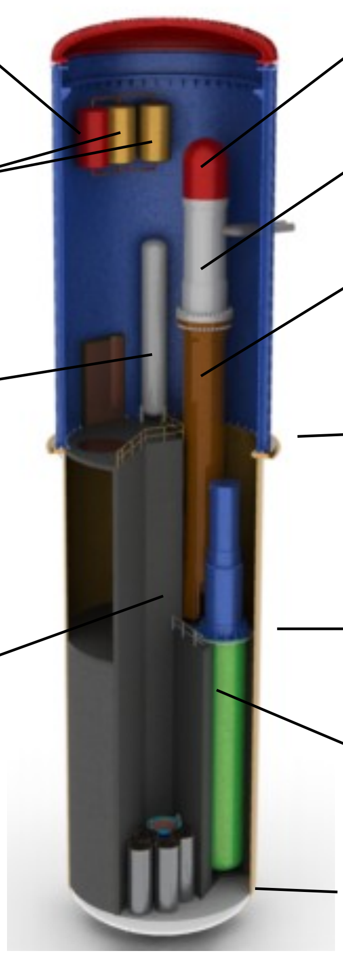
NuScale 12 Module Control Room



- *Notice 12 individual reactor stations and central plant station*
- *Currently envision 6 total staff: 3 reactor operators and 3 supervisors*
- *There is significant engagement ongoing with NRC staff (regarding application of its “NUREG-711” Human Factors Engineering Program Review Model) to determine appropriate staffing*

Holtec SMR

SMR-160 Primary System



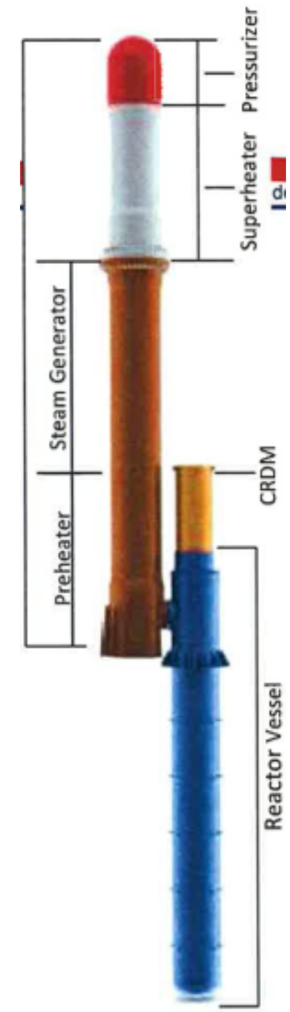
Single-batch cartridge core

- *Full core reload as a cartridge*
- *37 Full Fuel Assemblies*
- *14 foot high fuel*
- *Up to 8 different fuel assembly types*
- *8 burnable absorber segments per fuel assembly*
- *4.95 wt% fuel enrichment*
- *Reactor Control Rod Assemblies: Shutdown – 16, Reactivity Control – 17, Axial Shaping – 4*

SMR-160 Reactor Coolant System

- **No reactor coolant pumps**
- **Purely gravitational flow in all operating modes driven by heat generated in core**
- **No soluble boron in coolant**
- **“Black Start” capability***

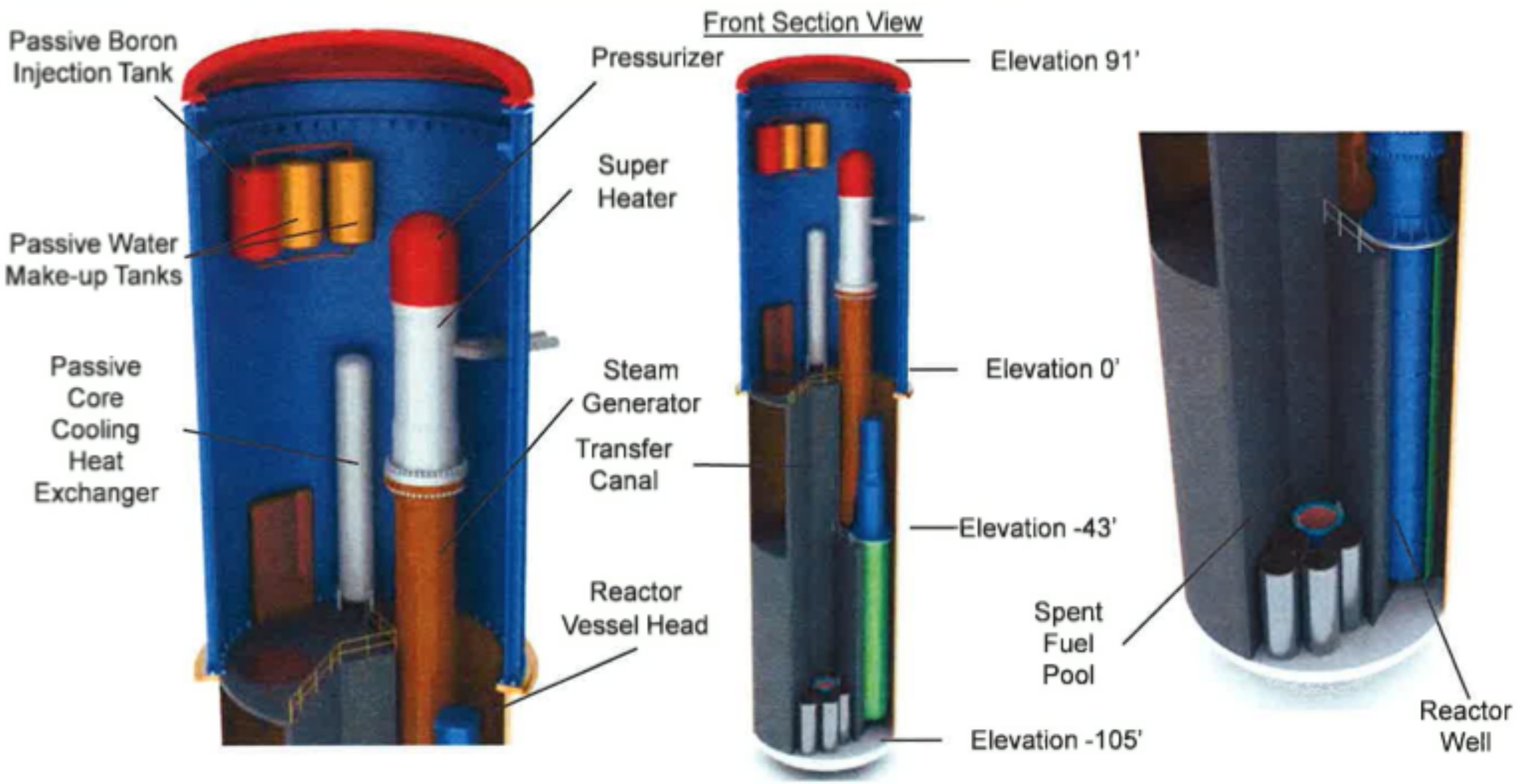
***Black Start means no need for off-site power**



The Rector Coolant System (RCS) “Stack”

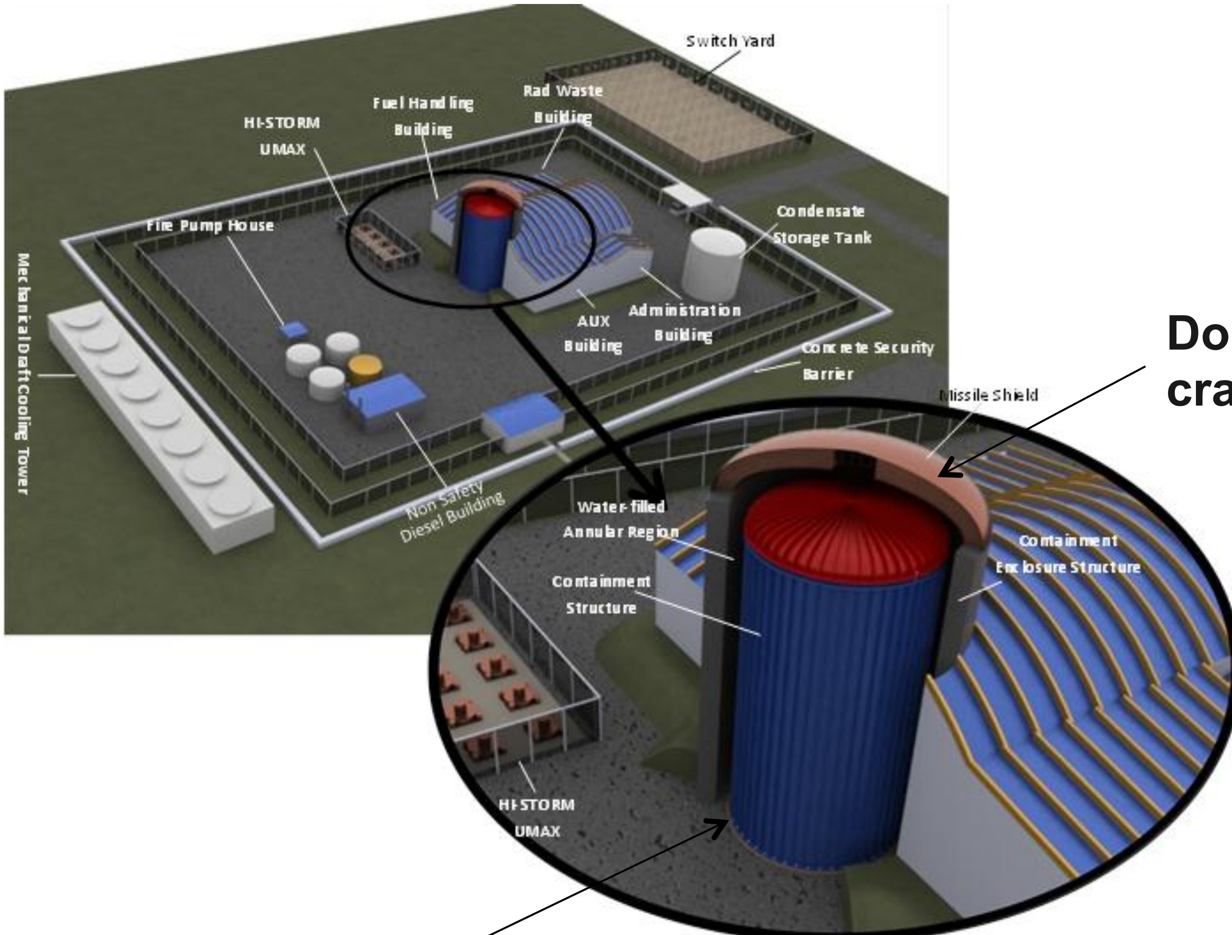
- *Steam generator and CRDMs are outside the Reactor Pressure Vessel (RPV)*
- *Steam generator is vertical, integrally connected to RPV*
- *Single stages of superheat in steam generator*

SMR-160 Configuration in Containment



- *Cavity around the RPV (reactor well) is flooded with water*
- *Containment diameter of 45 feet (relatively large diameter)*
- *Containment height of 196 feet*

SMR-160 Enhanced Physical Protection



Double protection against crashing aircraft

Underground location of safety systems

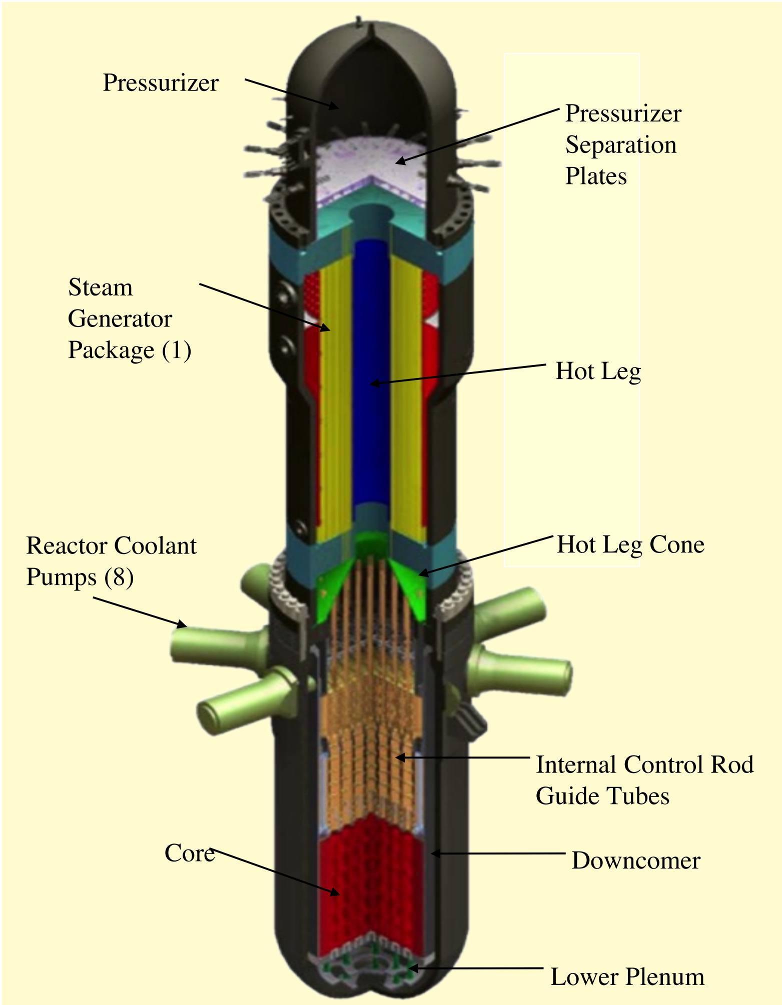
- *Immunity from external natural events*
- *Maximum protection from malevolent human intervention*

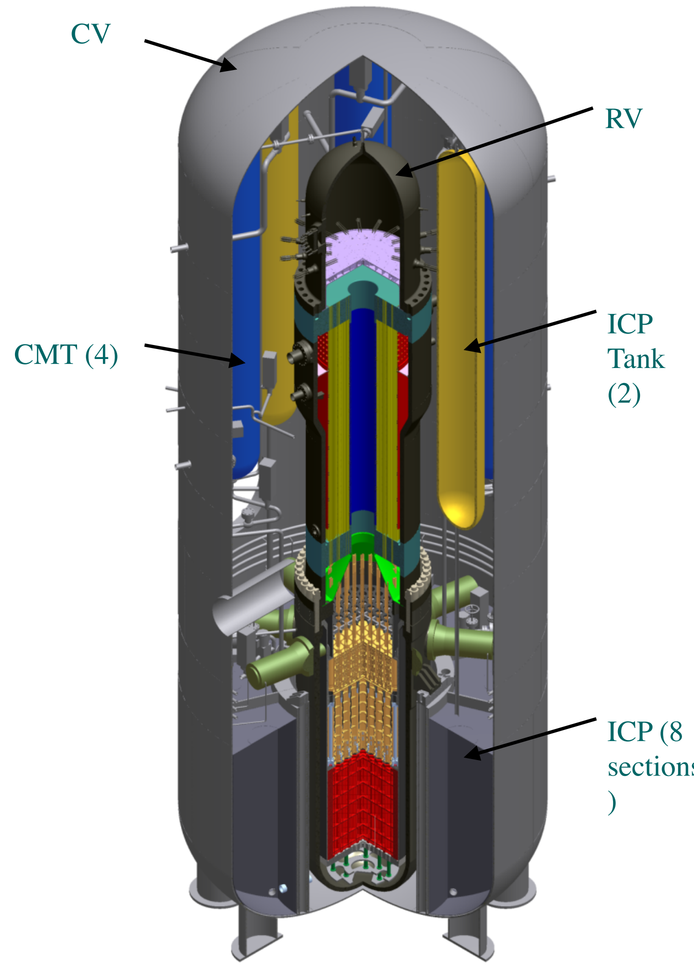
SMR-16 Safety Systems

- **Passive Core Cooling System (PCCS)**
  - Uses submerged bundle steam generator in containment and air-cooled condenser outside of the containment
- **Residual Heat Removal System (RHR)**
  - Lower pressure system used for normal shutdown in conjunction with the PCCS
- **High Pressure Core Injection System (HPCIS)**
  - Injects borated water at high pressure
- **Reactor Startup System**
  - Heats up reactor after fresh core load; integrated with RHR
- **Passive Spent Fuel (SFP) Cooling System**
  - Similar to PCCS (lower capacity, lower operating temperature)

Westinghouse SMR

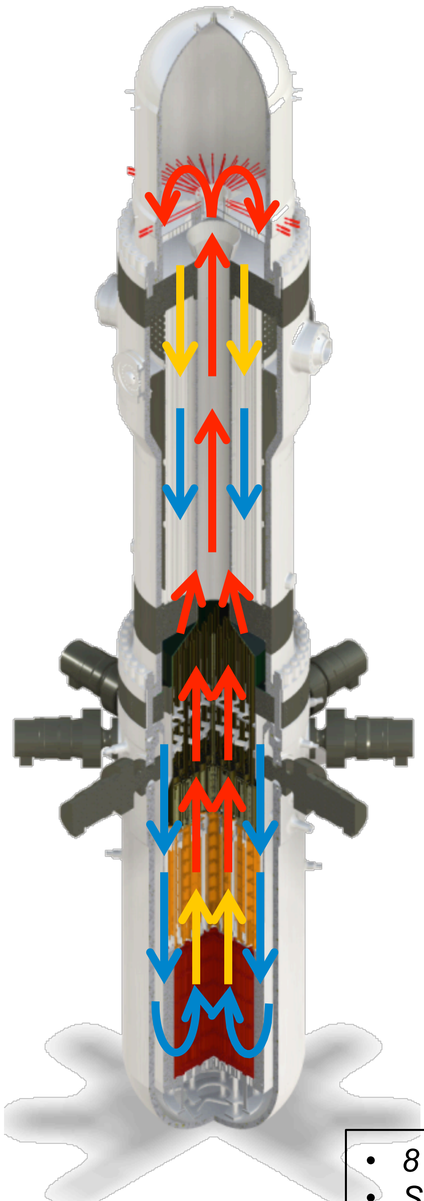
W-SMR Primary System

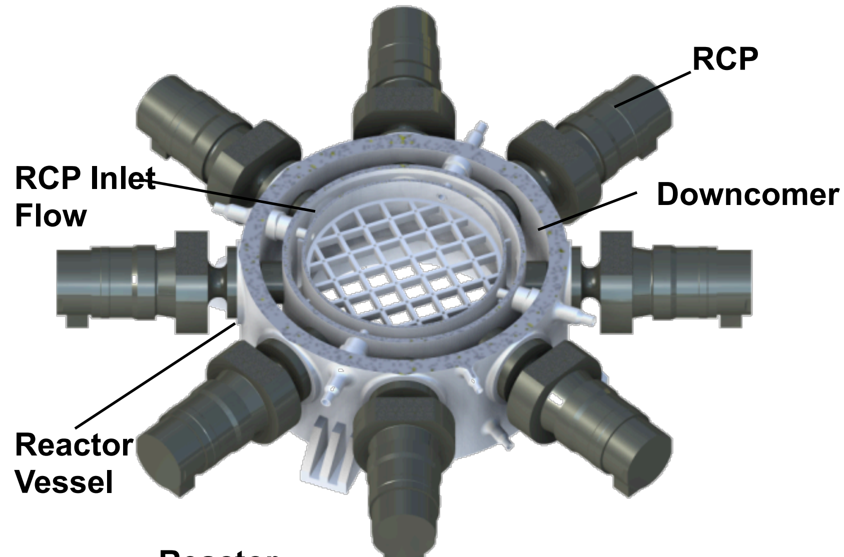


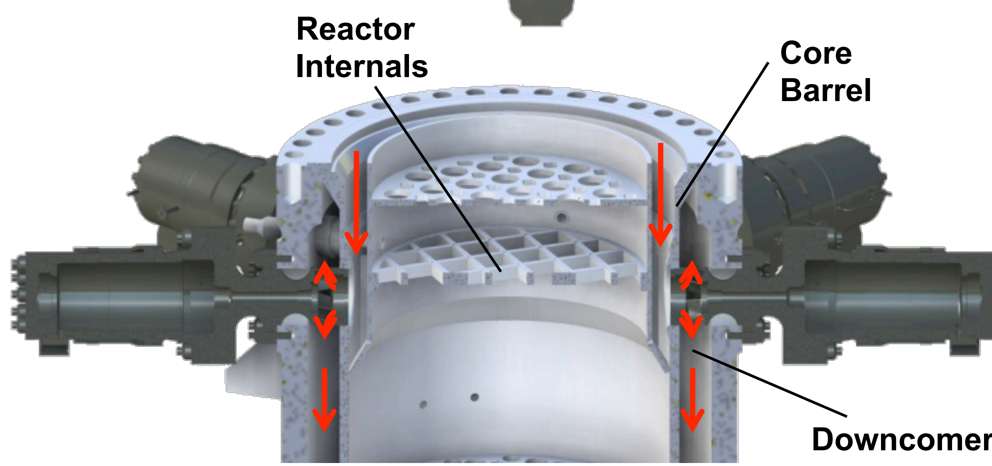


- *Stand alone unit – no shared systems*
- *8 foot active fuel length, compared to the normal 12 to 14 foot length of currently operating reactors*
- *RPV: 81 feet height, 11.5 feet OD, 280 tons upper vessel package (heaviest)*
- *Containment: 91 feet height, 32 feet OD, steel*
- *Containment is (1) high pressure (rated at 250 psig and operates at a partial vacuum to facilitate heat removal; (2) submerged in water; (3) fully modular and prefabricated*

W-SMR Coolant Flow Path

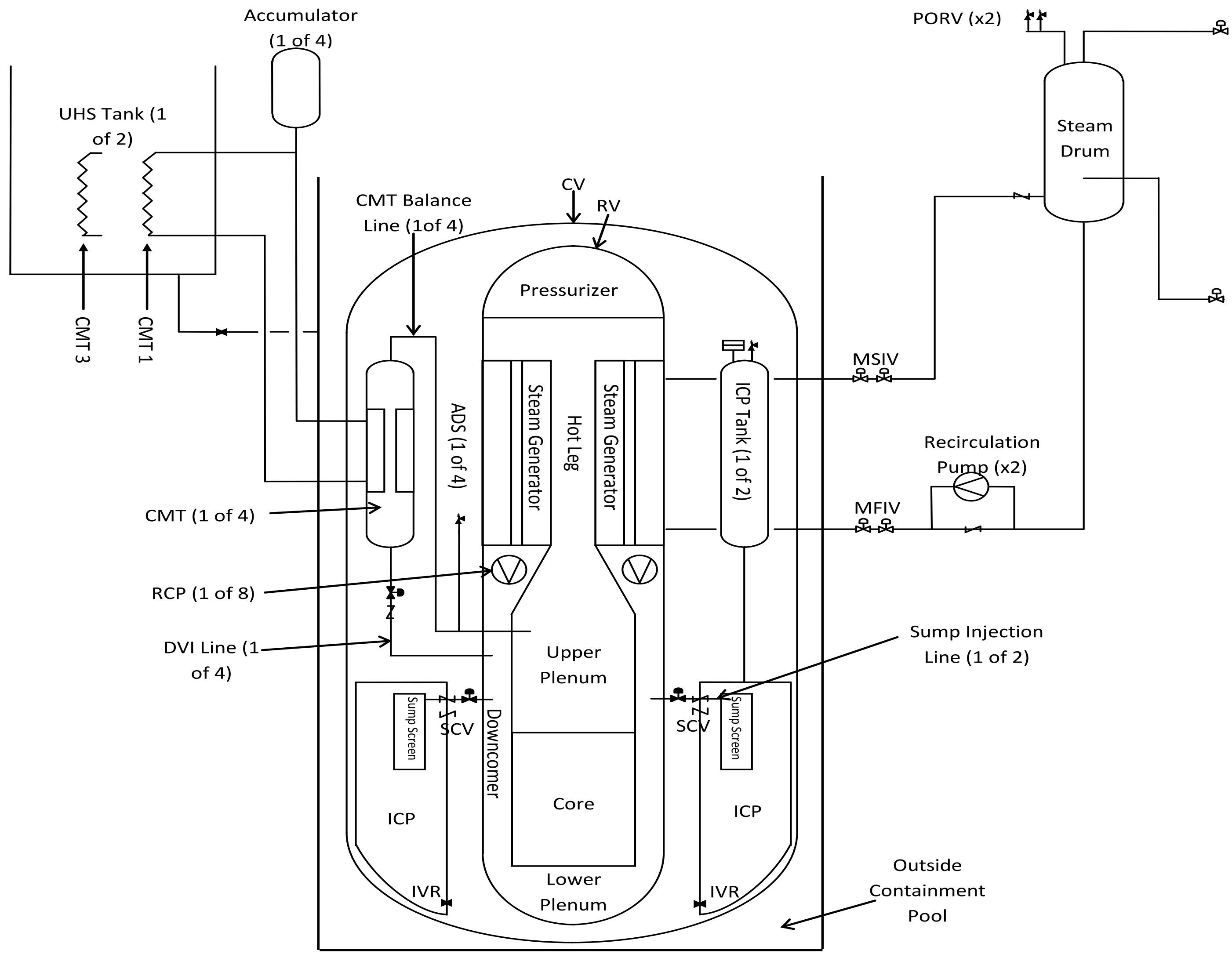






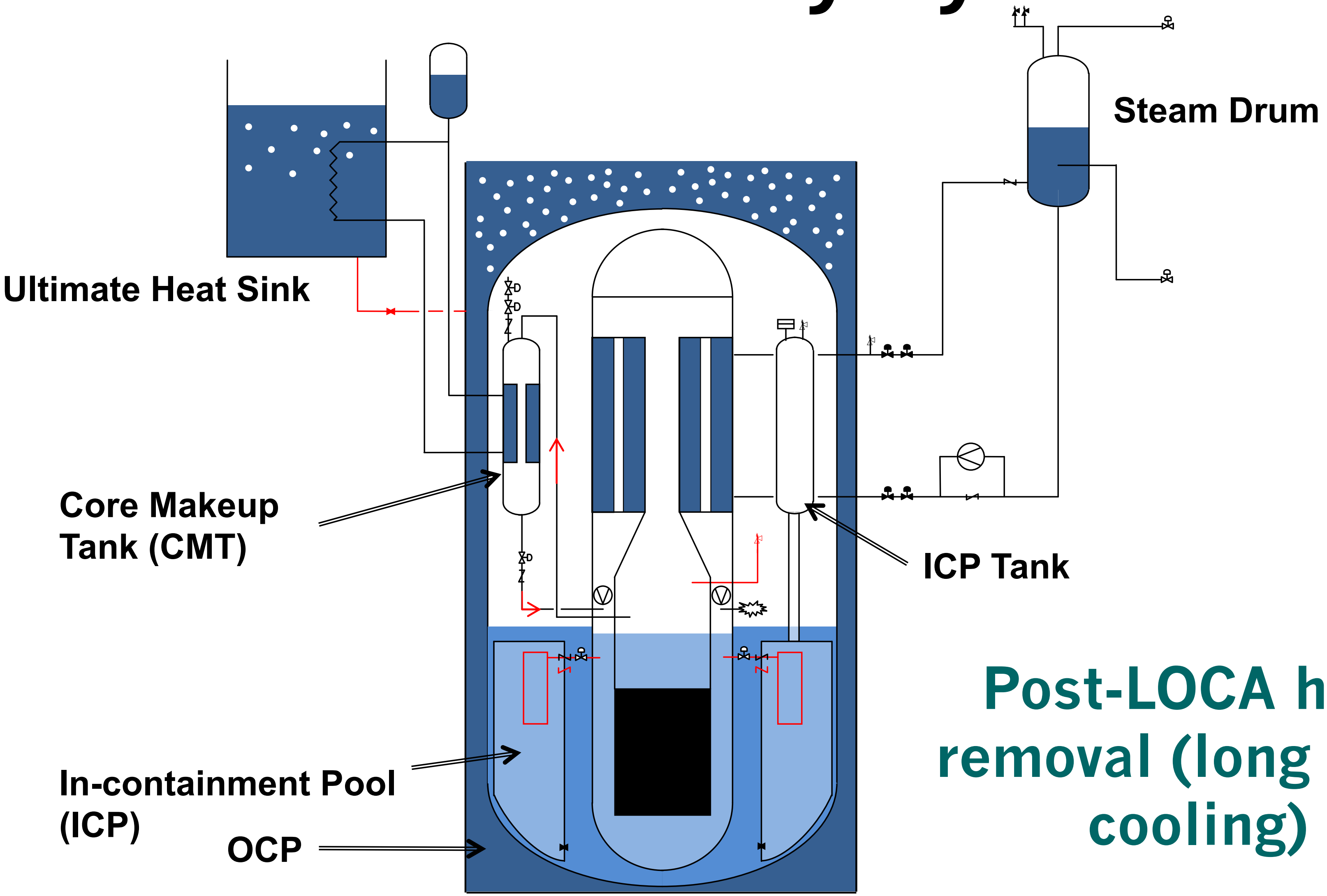
- *8 external horizontal seal-less pumps driven by variable speed drives*
- *Steam generator (1 unit) is recirculating, once-through, straight tube*

W-SMR Safety Systems



- *No AC power required for 7 days for plant safety – capability to add inventory to Ultimate Heat Sink (UHS) tanks for indefinite cooling*
- *100% reliance on natural forces: gravity, evaporation, and condensation*

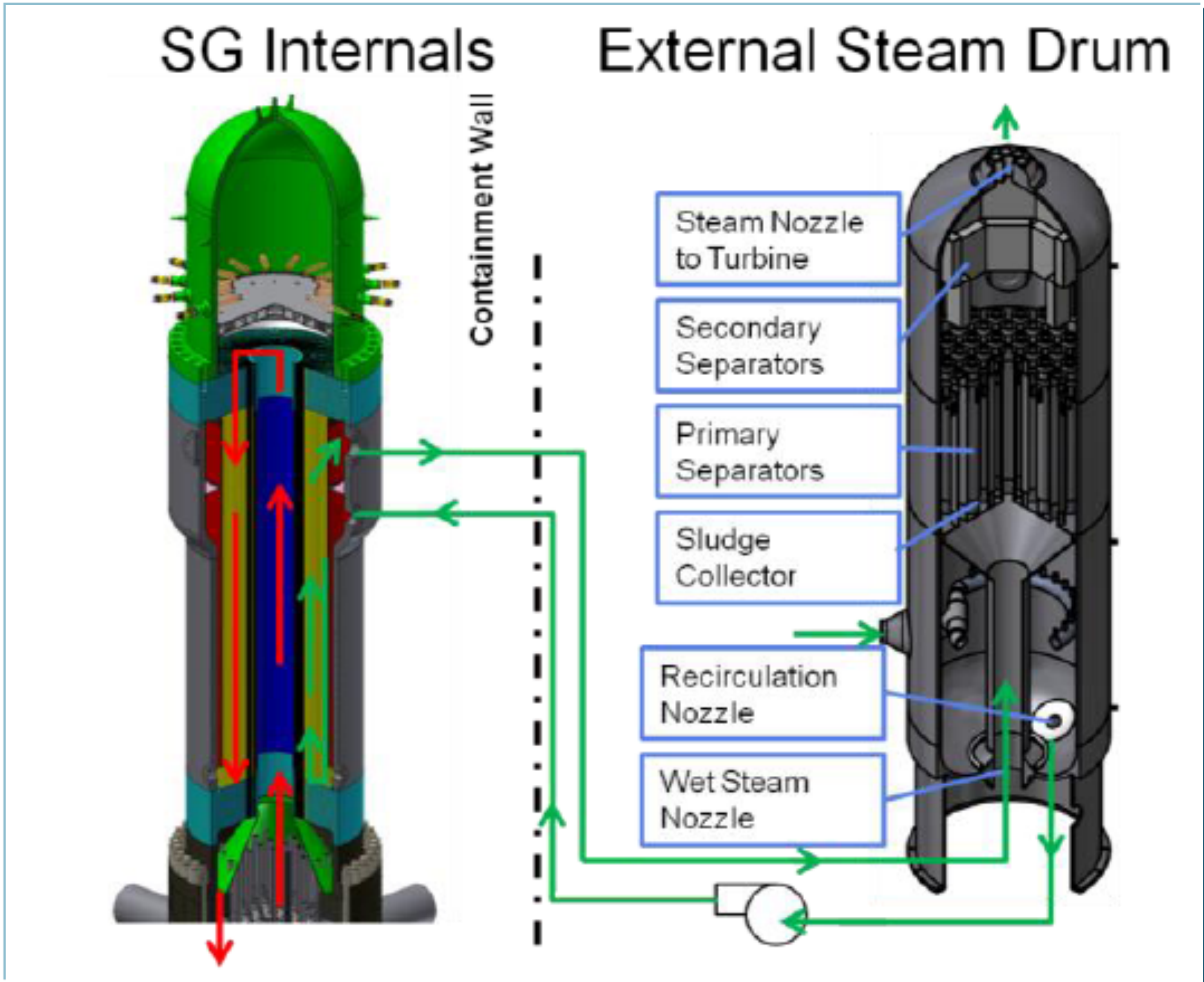
W-SMR Safety Systems



Post-LOCA heat removal (long term cooling)

- *CMT provides diverse shutdown, passive decay heat removal, and RCS inventory addition*
- *ICP provides cavity flooding and long term makeup to the RCS*
- *ICP Tanks allow gravity injection into the RCS once depressurized*
- *Ultimate Heat Sink provides passive decay heat removal via the CMT heat exchanger and inventory makeup to the OCP*

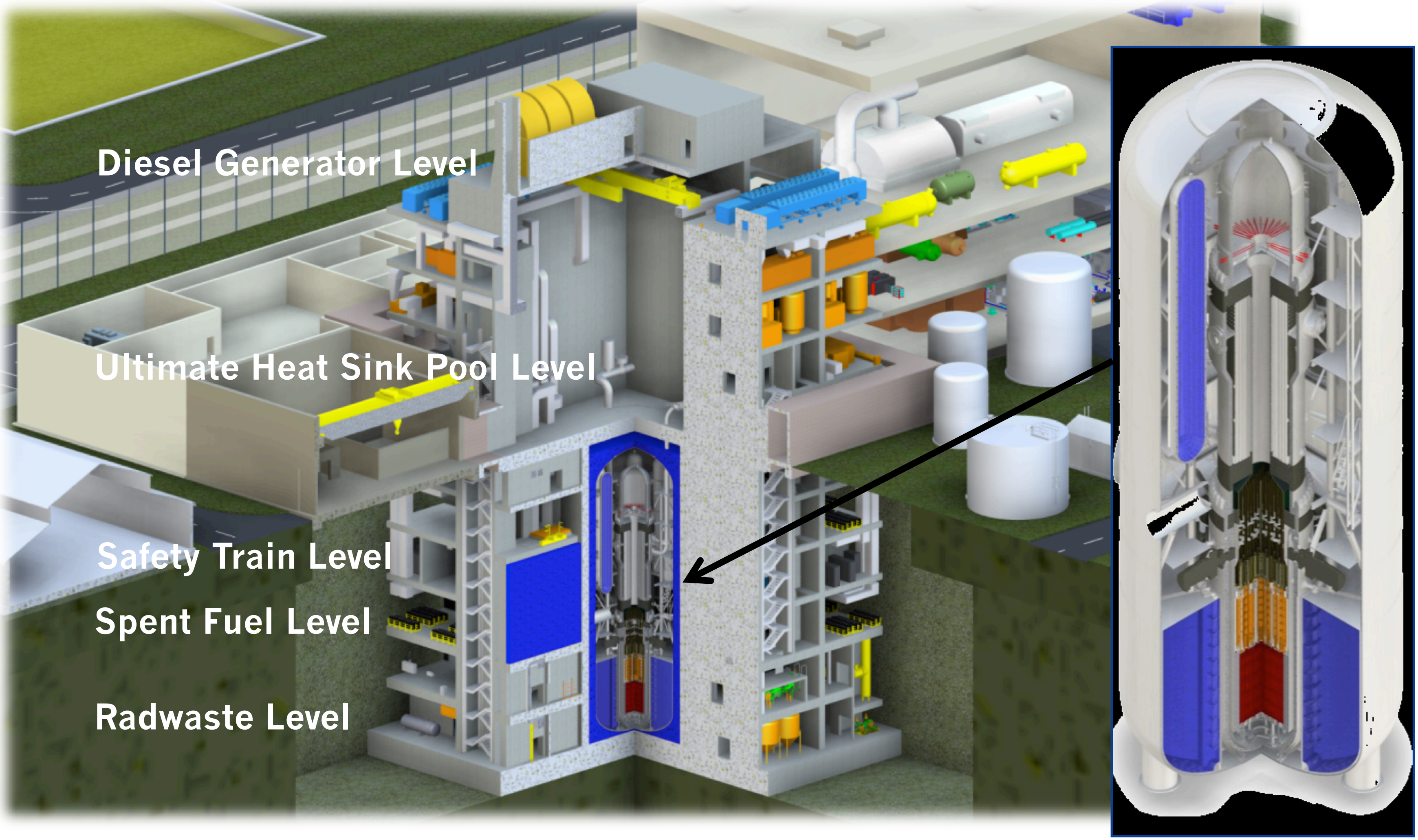
W-SMR Balance Of Plant
(steam drum for secondary inventory)



- **Eliminates dryout ⇒ allows compact SGs within RPV**
- **Increases water inventory on secondary side ⇒ lengthens heat removal through SGs in loss of feedwater event**

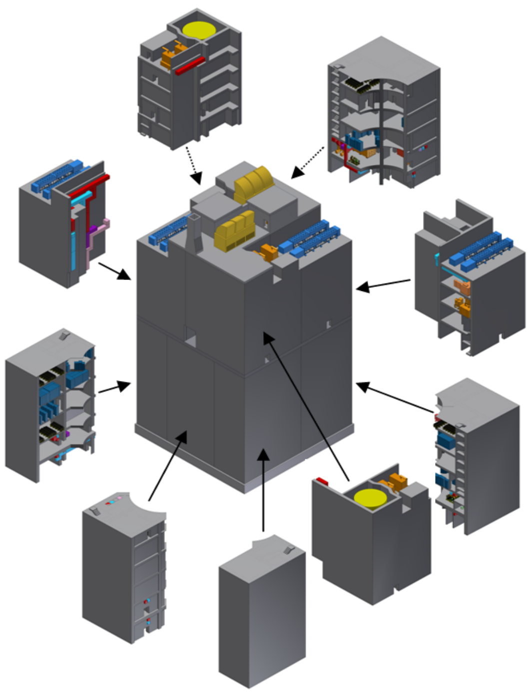
- *W-SMR has an external steam drum*
- *Rest of BOP is standard Rankine steam cycle with option for option for air-cooled condenser*

W-SMR Plant Layout

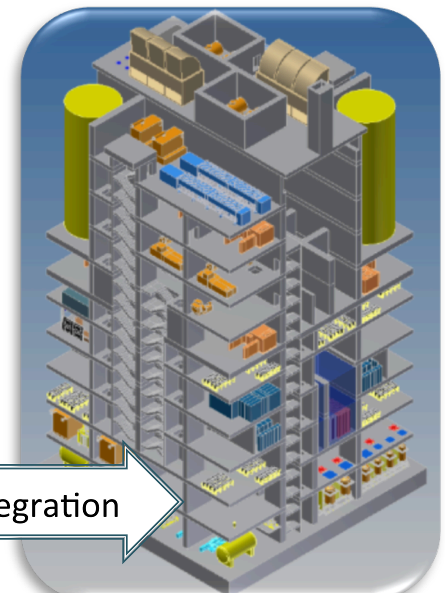


- *Total plant embedment is 110 feet*

W-SMR Modular Construction



Sub-modules forming the NSSS island – designed from the beginning

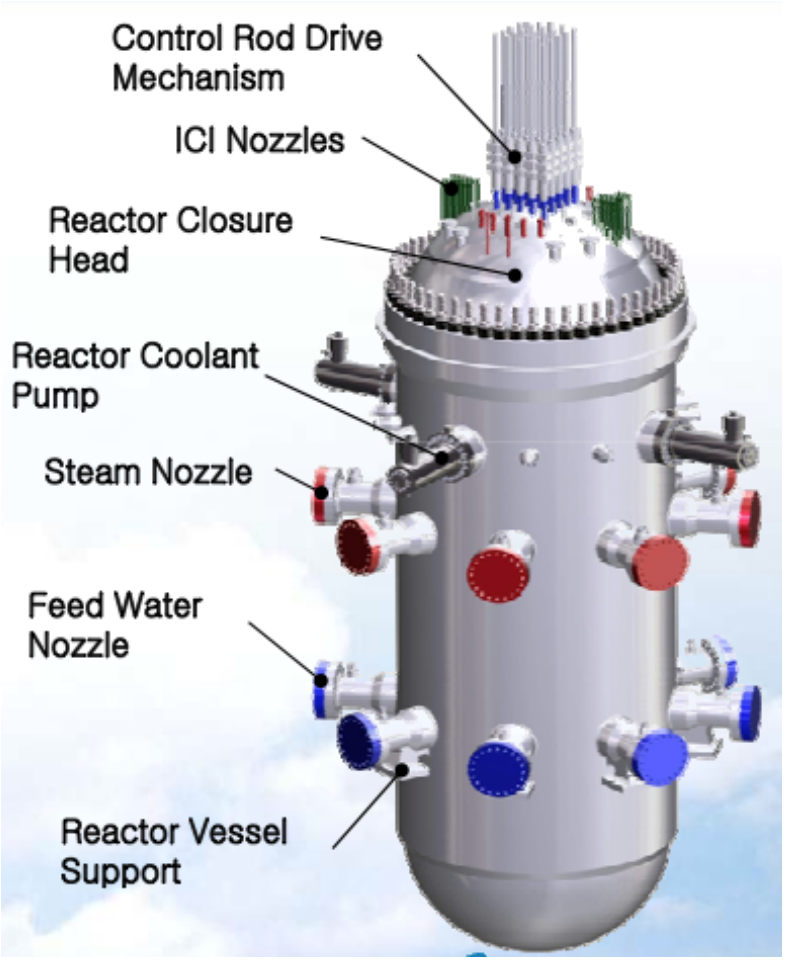


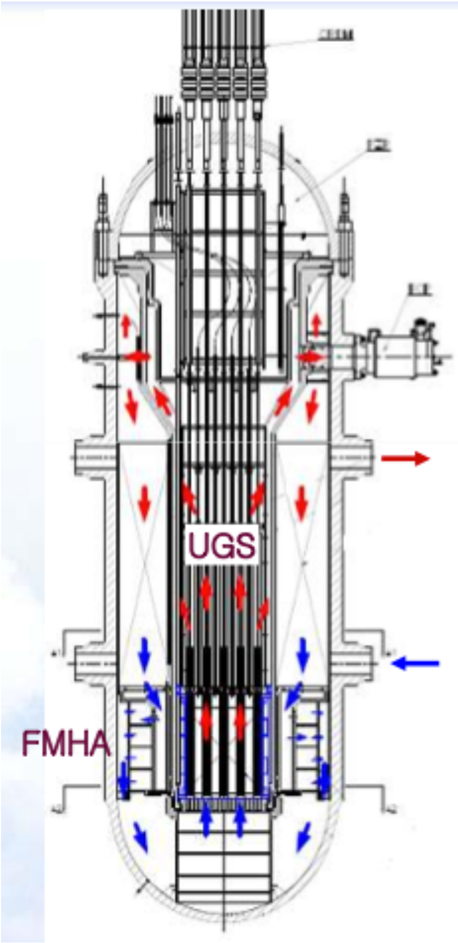
Modules Factory 1 → Shipping → Staging Area 3 → Handling → In Situ 8 → Integration

- *Entire nuclear island is modular design using composite steel structures*
- *Modular design drives work normally completed at the construction site to the factory where quality is better controlled, overall cost are reduced and schedule certainty increased*
- *All modules are designed for road and rail transport to site and scalable to other forms of transport*

KAERI SMR

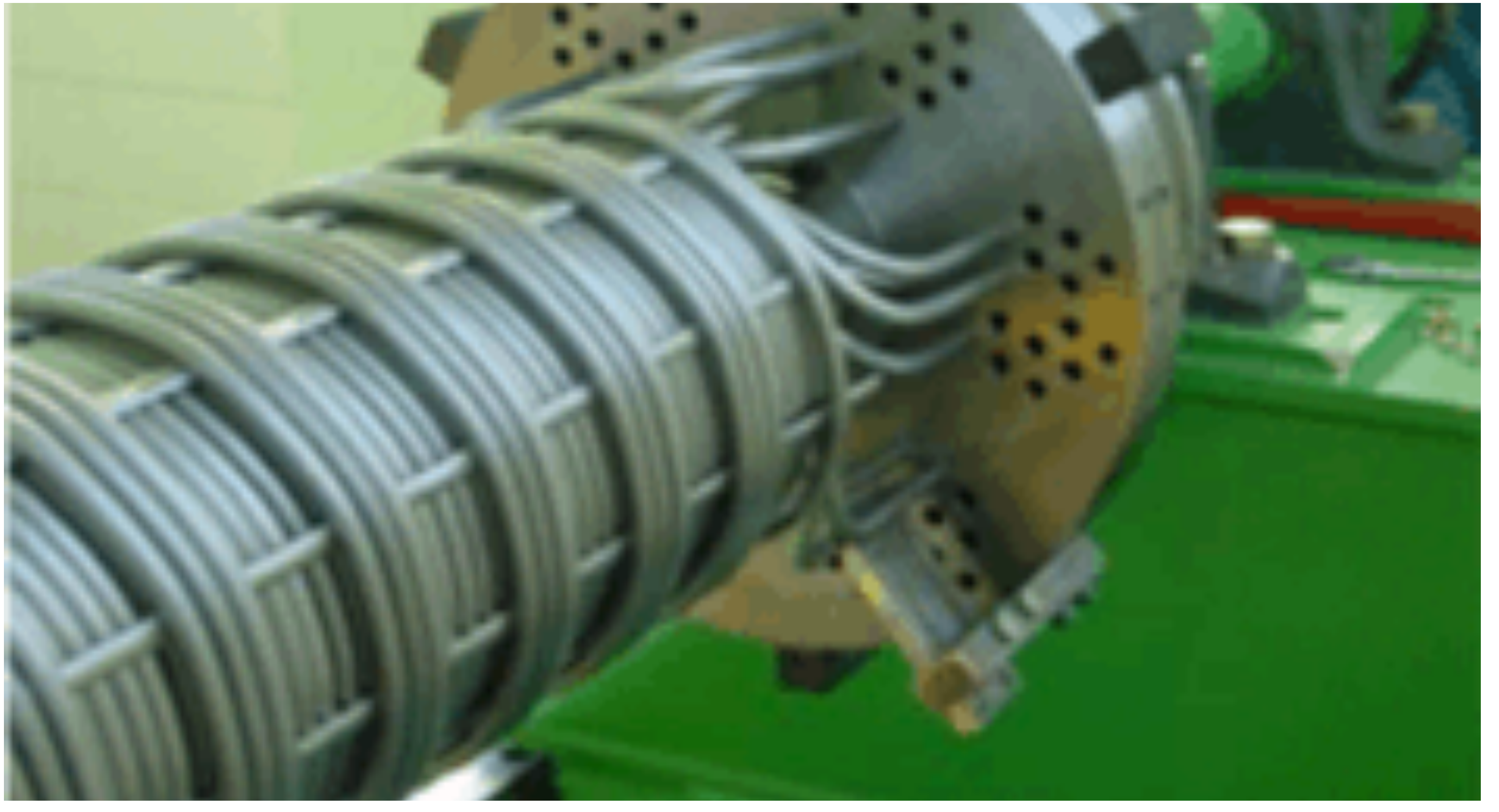
SMART Primary System





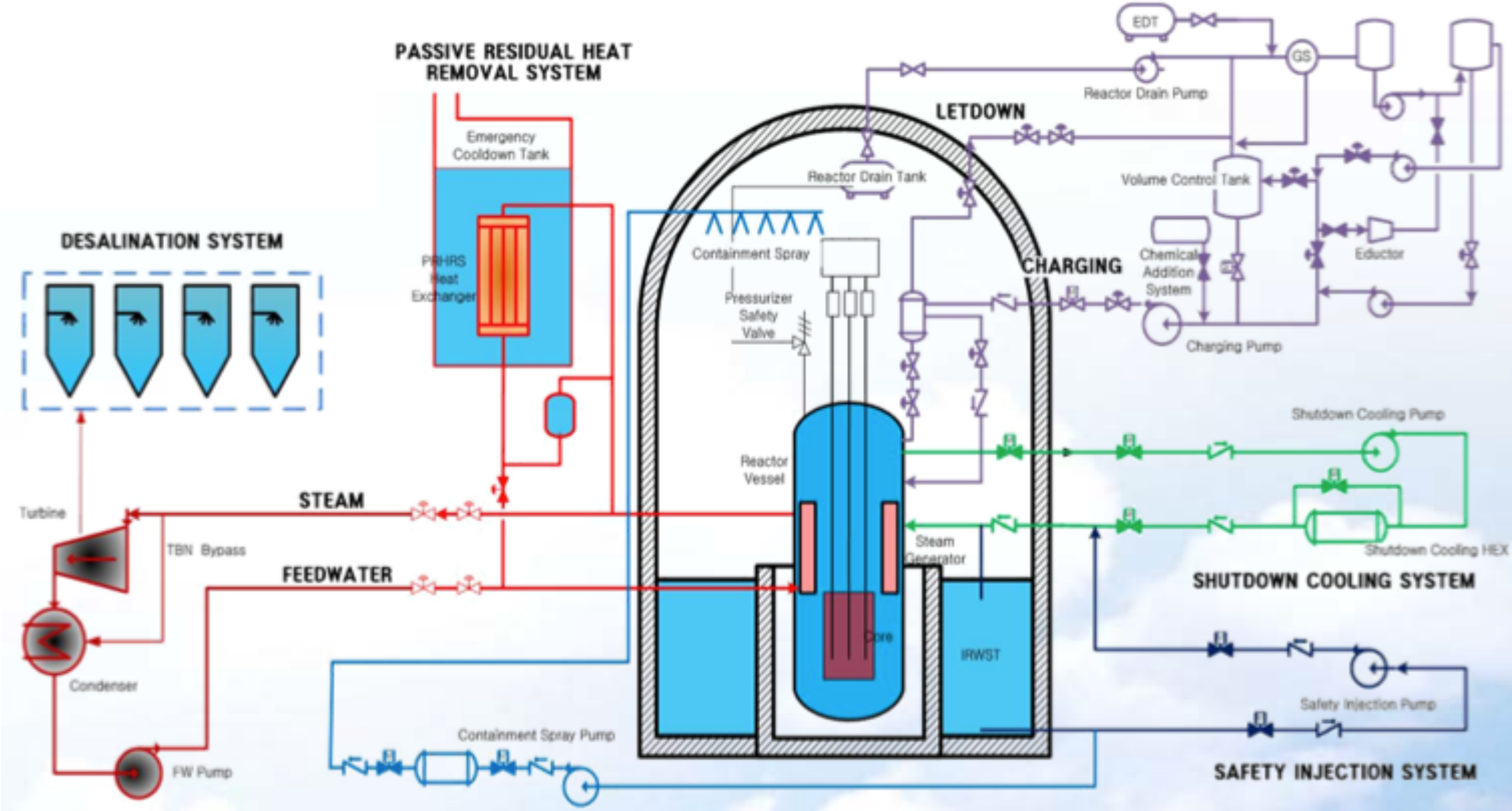
- *8 helical once-through SGs with 30 degrees C superheat*
- *4 canned motor pumps*
- *Internal pressurizer*
- *25 external magnetic jack type CRDM's*
- *RPV: 6.5 m diameter and 18.5 m height*

SMART Steam Generator



- *Reactor coolant on shell side and feedwater on tube side*
- *10 meters in height*
- *Some have been critical of the inspectability and maintainability of helical steam generators, but KAERI has performed eddy current tests to verify the inspectability of the design*

SMART Safety and Auxiliary Systems



- *Notice all the traditional active safety systems*
- *Has a passive Residual Heat Removal System on secondary side of steam generators*

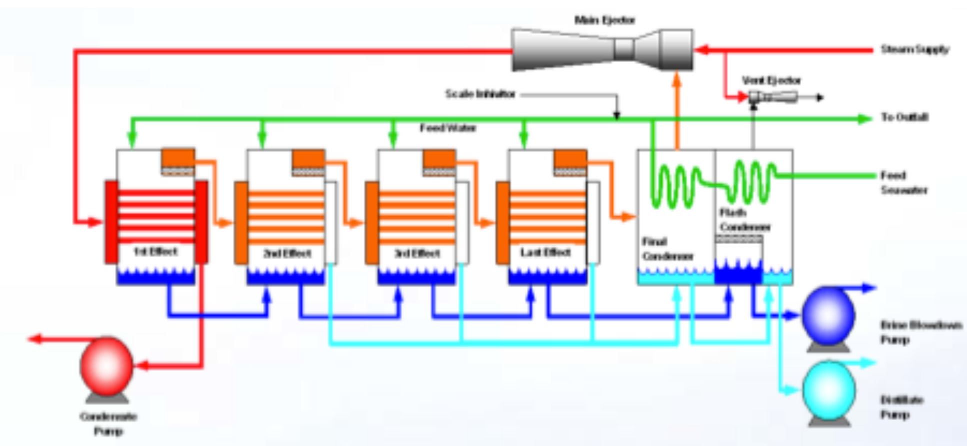
SMART Safety Systems

- **Passive Residual Heat Removal System (4 train)**
  - **Natural Circulation Cooling of SG from Secondary Side**
  - **Only need two trains operational to cool down the plant**
- **Safety Injection System (4 train active)**
  - **Direct Vessel Injection from IRWST**
- **Containment Spray System (2 train active)**
- **Shutdown Cooling System (2 train active)**

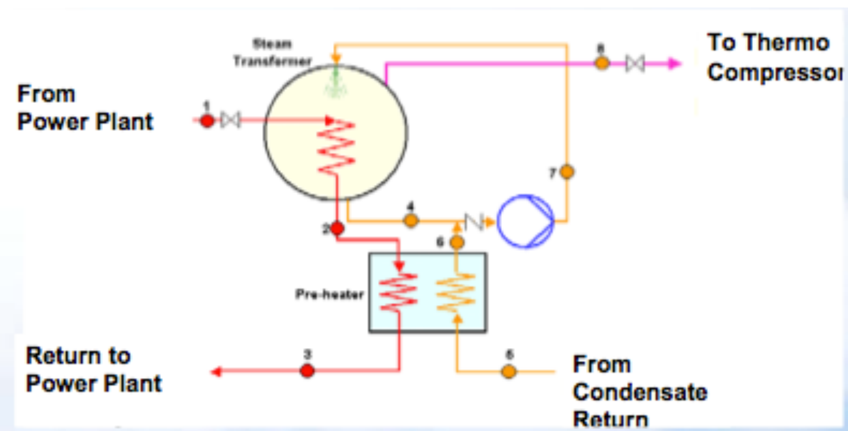
- *10 hour vital batteries*

SMART Co-generation for Desalination

- **Steam Transformer for isolation of potential radioactivity in secondary plant steam from desalinated water**
- **Steam is supplied from secondary plant turbine extraction**



Schematic Diagram of MED-TVC



Steam Transformer

- *4 units of "Multiple Effect Distillation Process with Thermal Vapor Compression" (MED-TVC) supply 40,000 tons desalinated water*
- *The MED-TVC evaporator is basically an MED evaporator fitted with a thermocompressor. The purpose of the thermocompression of the vapor is to take advantage of the pressure of the available steam, when this pressure is sufficient (i.e. above 2 bar abs), to enhance the units' performance.*