Small Modular Reactors – Providing Energy beyond the Grid

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RELAP5-3D is capable of modeling Small Modular Reactors and is already being used to analyze some.

Small Modular Reactors (SMR) concepts are currently in various stages of development. Current SMR designs incorporate innovative approaches to achieve design simplification, modularity, passive safety features, proliferation resistance, speed of construction, and reduced financial risk. Their deployment strategy allows for an incremental approach, thus reducing up-front capital requirements and being more suitable to limited grid capacity. The strategic goal for SMRs is to penetrate market sectors not being served by the current fleet of reactors and thereby demonstrate the environmental and economic benefits of nuclear energy to a broader community.

Although SMRs can have substantially higher specific capital costs as compared to large-scale reactors, they may nevertheless enjoy significant economic benefits due to shorter build times, accelerated learning effects and co-siting economies, temporal and sizing flexibility of deployment, and design simplification. Moreover, the market potential for SMRs extends beyond power production to various co-generation and advanced process heat applications.

SMRs are new to the energy industry, but have been used on U.S. Navy vessels for over 50 years. Naval reactors are typically pressurized water reactors that produce 50 to 300 MW(e), depending on the type of ship, and are refueled infrequently. Generating anywhere from 25 to 300 MW(e) depending on the design, SMR's rank as small in the IAEAs classification system, where a small reactor produces less than 300 MW(e) and a medium produces less than 700MW(e).

Some new SMRs are looking at advanced fuel cycles and innovative safety and operational approaches, which still need to be verified and validated with the help of Nuclear Regulatory Commission approved system codes, such as RELAP5, and further validated by experimental scaled prototypes.

RELAP5 has been used extensively for its various coolants, balance of plant, component models, and has successfully modeled thermal hydraulics characteristics (two-phase fluid, effect of non-condensables, etc.) with coupled neutronics for LWRs and advanced reactor designs, to understand the complete system performance with feedback. These capabilities are necessary to model SMR operational and accident scenarios and in SMR operator simulators. Thus, the vendors of different SMRs are employing RELAP5-3D for system design and adapting it for licensing calculations.

Many SMR designs are currently at different stages of development in the United States. RELAP5-3D has the flexibility to provide each SMR vendor with modeling capabilities necessary to meet their specific design and development requirements. Examples of how RELAP5-3D can be applied to each of these unique designs are as follows:

- *Integral Pressurized Water Reactor (IPWR) by NuScale Power*

NuScale's Integral Pressurized Water Reactor (IPWR) is a 45 MW(e) power module having its own combined containment vessel and reactor system, as well as own designated turbine-generator set, cooled by natural convection of water that can be shut down safely without pumps or other electrically powered systems. Up to 12 of NuScale's integral power modules can be assembled into one power plant to produce 540 MW(e).

Input has been developed to model NuScale using existing RELAP5-3D products. Work is being performed with RELAP5-3D using both a Fortran 95 and an older Fortran 77 version. Plans for a proprietary version of the code are underway.

- *mPower by Babcock & Wilcox*

mPower is a scalable 180 MW(e) integral reactor module (a loop plant incorporated into a single vessel) with long refueling cycles, located below grade, maintaining key features of conventional PWRs, featuring independent safety systems and a passive containment cooling system.

RELAP5-3D input models for the reactor have been developed. Plans are ongoing to create a proprietary version of RELAP5-3D from a recently released version. Studies are underway to determine the work needed to verify and validate the proprietary version for modeling mPower.

- *Energy Multiplier Module (EM^2) by General Atomics*

EM^2 is a modular 245 MW(e) high temperature, helium-cooled fast reactor located below grade that uses a traditional PWR steel pressure vessel. It is fueled with (in average) 6.5% enriched uranium carbide and has a 30-year refueling cycle.

RELAP5-3D has had the capabilities needed to model helium-cooled reactors and fast reactors for many years. The thermal properties of the fuel are needed, and these can be entered through user input.

Gen4Energy Reactor by Gen4Energy

Gen4Energy is a 25 MW(e) lead-bismuth eutectic cooled modular fast reactor. It is truck-transportable. The reactor is contained in a sealed cartridge that requires no onsite refueling. It uses uranium nitride fuel (less than 20% enrichment) and has a 10-year refueling cycle. It features passive natural circulation for decay heat removal from the reactor vessel.

RELAP5-3D has fluid property tables for a lead-bismuth coolant. The thermal properties would be necessary to enter through input for uranium nitride.

- *Thorium-Fueled Fast Reactor by Westinghouse*

The Thorium-Fueled Fast Reactor is a 410 MW(e) sodium cooled fast reactor. It is designed for advanced fuel cycles that include the transmutation/utilization of transuranics, and uses thorium–transuranics oxide, nitride or carbide fuel (the transuranics isotopic vector corresponds to used LWR fuel).

RELAP5-3D has fluid property tables for a sodium coolant. The thermal properties for these fuels would be necessary, but can be entered through user input.

- *Power Reactor Inherently Safe Module (PRISM) by GE Hitachi*

PRISM is a 300 MW(e) modular sodium cooled pool-type fast reactor that is transportable via truck or rail. It is fueled with uranium-transuranics-zirconium metal alloy fuel. It features passive decay heat removal from the reactor vessel. PRISM can be co-located with a small recycling center, and its flexible reactor physics design characteristics allow utilization either for breeding or waste management purposes.

Besides sodium fluid properties, RELAP5-3D has the ability to couple with other computer programs, such as containment, CFD, and instrumentation and controls programs, to solve complex problems through its PVM Executive. This ability may prove useful for modeling the application of PRISM to waste management.

Super-Safe Small and Simple Reactor (4S) by Toshiba-Westinghouse

Transportable via truck or rail, 4S is a 10 – 50 MW(e) sodium cooled fast reactor located in a sealed vault below grade. The fuel is uranium-zirconium metal alloy (uranium enrichment below 20%). 4S has a 10-year refueling cycle and the plant design life is 60 years. It features passive decay heat removal from the reactor vessel.

- *Traveling Wave Reactor (TWR-P) by TerraPower*

TWR-P is a 600 MW(e) reactor aimed at demonstrating the “traveling wave” reactor (TWR) design concept (depleted uranium as primary fuel after the startup core, closed fuel cycle, no waste reprocessing, breeding its own fuel from an initial starter metallic fuel containing ^{238}U and ^{235}U).

As mentioned above, RELAP5-3D has the fluids, components, and other features necessary to model these kinds of reactors.

Many other SMR concepts being studied outside the U.S. should be mentioned:

- New Technology Advanced Reactor Energy System (ANTARES) by Areva, France (high temperature gas cooled ~300 MW(e) reactor)
- KLT-40S and ABV by Rosenergoatom, Russia (floating modular reactor concepts)
- SVBR-100 by En+, Russia (lead-bismuth eutectic cooled 100 MW(e) fast reactor without onsite refueling)
- SMART by KAERI et al., Korea (100 MW(e) integral PWR reactor)
- CAREM by CNEA, Argentina (25 MW(e) integral PWR reactor)

For many reasons, SMRs have a bright future in the nuclear power generation industry. RELAP5-3D will be of great use in modeling them and in developing simulators for training plant operators .