Novel Device for Enhanced Access to Ultimate Heat Sink for Reduced Cost and Risks and Accelerated Site-Neutral Deployment of Advanced Reactors

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ABSTRACT:

A team of researchers at two universities and a national laboratory is combining talents to make possible and accelerate site-neutral deployment of advanced reactors while reducing cost and risks. This will be achieved by finalizing the design of a proposed path to Ultimate Heat Sink (UHS) device and demonstrating its effectiveness to remove reactor residual heat at larger rates without the need for water or access to other cooling means.

The maximum achievable safe power in nuclear reactors is a fixed multiple of the initial shutdown decay heat generation rate. Also, ultimate safety hinges on the capacity to remove decay heat from the core fast enough to prevent fuel and/or cladding (if a cladding is adopted for the fuel) damage. Investment safety also imposes no damage to the reactor vessel. Current state-of-the-art research on decay heat removal assumes passive vessel cooling via natural circulation/convection of air or water, or alternatively counts on the thermal inertia of a massive water inventory, liquid metal inventory, or graphite inventory.

This project will complete and optimize the design of a recently patented heat removal concept/device for nuclear reactors. The new device will be examined and demonstrated via modeling and prototype components construction and testing. A new passive- and inherent-mechanism for off-normal-condition decay heat removal will be considered. A unique feature in these new approaches is the absence of a need for any convective heat transfer or coolant fluid, in contrast to the above traditional approach examples and other generation-III-plus and Generation-IV reactors. The new concept is independent of reactor core design and could enhance many advanced reactors that are currently under development. The project goals are to (1) enhance reactor safety, (2) increase achievable safe power levels, which improves the economy of reactor plants, (3) reduce capital costs per unit of generated energy, and (4) free the plant from site-specific deployment constraints, which eases and speeds up deployment to any desirable location feasible. In practice, it is proposed to modify the interface between the reactor vessel and the (outer) wall of the reactor cavity and allow inherent transition from axial to enhanced radial heat removal into the surrounding ground or to air radiators. Engineered modifications between the reactor cavity wall and the near field are also proposed. Because of goal (2), this project will be considering a reactor with a primary coolant that has a greater volumetric heat capacity than gas-cooled reactors and for which the benefit of increased core power density and total core power level on the same footprint (and nearly the same initial capital investment) could be actually realized.. At a minimum we will consider and experimentally test water and molten salt coolants. We will also consider a liquid metal or a surrogate for a liquid metal depending on the availability of an environmentally isolated test

location. In addition to the experimental demonstrations, the project will simulate one reactor with high thermal inertia (e.g., high temperature gas cooled reactor (HTR)) and two types of advanced reactors that have relatively low core and vessel thermal inertia (high temperature molten salt-cooled reactor (FHR) and liquid metal cooled reactor (LMR)). We will use the models developed and validated by the experimental data to demonstrate the enhanced safety margin. In this regard, potential target typical reactors would be one similar to the Kairos Power FHR (KP-FHR), one like the Next Generation Nuclear Plant Very High Temperature gas-cooled Reactor (NGNP-VHTR), and two generic reactors (a sodium cooled reactor and a water cooled reactor).

The proposed developments are responsive to the objectives of the solicitation in multiple complementary ways. A new and innovative component is proposed to be incorporated into the design and construction of nuclear power plants. The new component is simple enough that it should have a very high Technology Readiness Level in short order and would be suitable for deployment with any of the modern advanced reactors currently under development. The new component makes the reactors much safer and hence provides the means to reduce the financial risk of nuclear power plant ownership. The new component is fail-safe because, with the appropriate materials selection, its failure modes are actually safer than its normal operating condition, though in the failed states economic advantages would disappear and repairs would be needed. In its normal state, the new component will contribute to a significant improvement of the economics of power generation. Indeed, it allows an increase of the reactor total power on essentially the same footprint, which would translate into a net decrease of the capital cost per unit of the energy generated, and thus result in a lower levelized cost of electricity (LCOE). For the same reasons, the Operations and Maintenance (O&M) costs per unit of energy produced would be effectively reduced.

Most importantly, the siting requirements for a reactor equipped with the new device (and using TRISO-based fuel) will be significantly facilitated as the increased safety will imply a reduced exclusion zone compared to that of the same reactor without the new device. This will make siting such a new reactor acceptable near population centers and at locations formerly used by coal power plants. But the ease of siting goes beyond, as relaxing the requirement of large inventories of auxiliary vessel cooling water or continued access to other vessel cooling means would result in the possibility of siting reactors fitted with the new component essentially anywhere on Earth. This in turn makes deployment significantly easier as the plant would essentially be site neutral.

In this project, the impact of the new path to UHS device on the LCOE will be assessed in a scoping analysis.

The proposed experimental testing and modeling for scaled-down systems or components of the various reactor types considered in this project will provide valuable data and experience to support the demonstration, review, and consideration of the regulatory aspects of qualification, inspection, and monitoring of the new device.

The broader impact of the device includes acceleration of the deployment of high temperature advanced reactors, including SMRs and microreactors. Two types of advanced reactor technologies that will benefit the most from the device are those (1) with the ability to generate a relatively high core power density with coolants capable of high heat capacity and removal rates (such as molten salt or liquid metal reactors) and (2) advanced reactors with low thermal inertia (e.g., gas-cooled fast reactor) in which case the main benefit will be enhanced safety.