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Developing the technical basis and risk assessment tools for flexible plant operation

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Program: LWRS

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ABSTRACT:

Nuclear energy, our largest ultra-low carbon electricity source in the United States[i], continues to be our most valuable tool in combating global climate change. However, energy needs go beyond base-load electricity applications and include a potential focus on alternative process heat applications, a major contributor to carbon emissions. To compete with natural gas, nuclear energy must also be an effective, flexible, and efficient energy source. Nuclear energy is potentially well suited to unique applications or flexible missions, including efficient and cost-effective integration with non-electricity generating applications, such as desalination, synfuel production, hydrogen production, and process heat for petrochemical and related industrial processes. Such co-generation options create additional revenue streams for economically challenged nuclear power plants (NPPs), improving the economic viability of these legacy facilities. Additionally, the need for intelligent apportionment of energy in complex systems is highlighted by the 2021 Texas power crisis. There are inherent challenges and regulatory concerns associated with expanded application of the existing fleet of light water reactors (LWRs) to support grid and off-grid applications. This proposal directly addresses those challenges to enable flexible plant operation and generation (FPOG) by:

1. Focusing on flexible operation of nuclear energy by improving integration with other energy sources, including advancing the technology readiness of control capable of dividing thermal and electrical power to support electricity grids while increasing plant revenue.
2. Understanding limitations of operator-led manual actuation of flexible plant systems to identify where automation is necessary or beneficial.
3. Developing and applying general and plant-specific light water computational tools that can be used to help design, test, and optimize dynamic thermal energy extraction and delivery and electricity dispatch. This includes normal operation, anticipated operational occurrences, and accident scenarios.
4. Extending probabilistic tools to include new initiating events introduced by new grid-to-plant process controls and plant-to-hybrid process controls coupling.
5. Developing and demonstrating at a bench-scale operational modalities using smart valve flow controllers as an example of smart instrumentation and data analytics for hybrid plant operations.
6. Developing and testing cybersecurity approaches for securing smart valves during online operation and enhancing in-depth plant digital security.

7. Developing an intelligent platform for real-time management of a Integrated Energy System (IES) by utilizing artificial intelligence (AI) tools to enhance the functionality, flexibility and resilience of the system ensuring the economic viability of IES operating within a grid balancing area to support electric and non-electric users.

This is a highly synergistic cross-cutting design effort leveraging the capabilities and technology of the US DOE-NE Light Water Reactor Sustainability (LWRS) program and the Integrated Energy Systems (IES) program. In addition, this proposal is supportive of the Department of Energy's Hydrogen Shot goal to reduce the cost of clean hydrogen to $1 per kilogram within one decade[ii]. This includes hydrogen generated with electrolysis from light water reactors (LWRs)[iii]. We will also leverage synergistic efforts related to high burnup fuel[iv] and concomitant extended LWR cycles[v], to ensure that the conclusions we gather are relevant to the most current and/or envisaged LWR operational paradigms.

The proposed RD&D includes modeling of LWR-driven hybrid energy systems that will enable penetration of nuclear energy into traditionally non-nuclear markets. The proposed effort is also highly relevant to the development of LWRs for application to chemical processes, and co-generation along with renewables. This effort will improve the performance and efficiency of LWRs and hybrid nuclear energy systems. The scalable dynamic models with control systems are a significant research need for such coupled systems to enable exploration of operational performance, optimization, reliability, and safety. Chemical process plants are more accident prone than nuclear plants. Penetration of nuclear energy into traditionally non-nuclear markets requires licensing of the chemical process facilities to nuclear safety standards. Licensing of a LWR driving a chemical process would be complex, and this study will act as a key milestone toward achieving this goal.

Many existing NPPs in the US are modernizing in order to efficiently operate beyond their original design and license lifetimes. These modernizations include increased digitization and automation of non-safety systems like turbine control. U.S. nuclear power is highly regulated, and operation is generally conservative, preferring human-initiated actions over automation. The plants were originally intended to operate at full power between 18 or 24-month fueling cycles. As the electrical grid is modernizing nuclear plants are seeking flexible plant operations and generation strategies to remain competitive in dynamic energy markets. Existing nuclear power plants are not well-suited to load-following on a daily basis. Because fuel costs are low, the operational costs are roughly equivalent whether the plants operate at full power or less than full power. One potential solution is to transition heat from electrical production to non-electric applications while maintaining reactor power at 100%. These new concepts of operation will require operators to adopt increased automation while ensuring reliable human performance and efficient hybrid operations.