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Sandia Nuclear Cartridge Concept

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Introduction

Nuclear power offers the promise of long-term electrical power for remote areas. Recent advances in passive safety and long-life cores make a reactor that can be operated autonomously for 20 years or more a real possibility. This white paper discusses a reactor concept that offers the potential for further development, resulting in a permanently hermetically-sealed "nuclear cartridge." The term "nuclear cartridge" is meant to imply a nuclear energy source that can be inserted into a site and operated autonomously until its energy has been depleted, then withdrawn and replaced by another cartridge. The concept can be scaled for various sizes, ranging from about 1 megawatt-electric (MWe) to about 100 MWe. The paper also discusses the concept of Integrated Safety, Operations, Security, and Safeguards (ISOSS) by design as it applies to this reactor design. Finally, a discussion of smart grids and how they can benefit the transfer of power to the end user is included.

The Nuclear Cartridge concept has been developed with the following characteristics in mind: highly reliable autonomous operation coupled with international monitoring, requiring minimal on-site operations personnel; walkaway passively safe design; cartridge replacement cycle on the order of 20 years; load following capability[1]; physical security by design requiring minimal security personnel during operations; and proliferation resistance by design. As illustrated in figure 1, integrating the reactor with advanced power conversion, smart grids, and other sources of energy results in a resilient and sustainable energy source.

[1] Load following may be implemented via smart grid technology if the physics of the reactor design do not support inherent load following capability.

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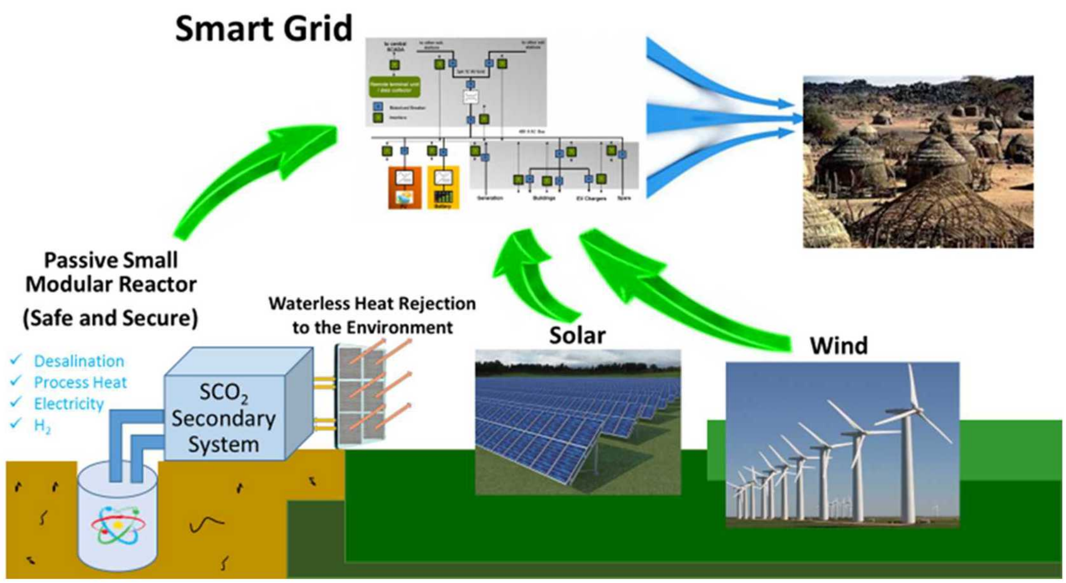

High-level Plant Design and Life Cycle Considerations

The reactor is a breeder/burner reactor. There are multiple ways to achieve the desired result. One approach is the so-called “candlestick” reactor design. In this design, one end of the fuel is fissile material, while the rest of the fuel is initially fertile nuclear material. As the fissile fuel is burned, transuranic mutation converts the neighboring fertile material into fissile material. A reflector is positioned around the fertile material at all times, but is designed and operated such that it does not allow too much of the fuel to be in the zone that is fissioning. As the fissile fuel is depleted, the reflector moves into the next zone which is now fissile and the process repeats until all the fuel is used. At the end of the life of the reactor, the most recently burned region will be highly radioactive, but the majority of the fuel will have cooled to some extent [Smith, et al, 2008]. Another design that has been proposed is the “traveling wave reactor” [Hejzlar, et al, 2013]. Once the first cartridge has been used, the reactor will remain in place until the radionuclides have decayed to the point that it can be extracted and moved to permanent storage. In the meantime, a second cartridge will be installed nearby, continuing to provide power to the region.

Whatever the final design of the reactor, it is likely that some form of liquid metal (e.g., Na, NaK, Pb, PbBi) will be used as the coolant. The reason for this is that liquid metal cooled reactors operate at low pressures and this is a major safety concern. A study to understand the benefits and drawbacks (e.g., toxicity, corrosion, fire hazards, pumping power required, freezing point) of the various potential coolants will need to be completed. The most likely power conversion cycle will be a supercritical carbon dioxide (sCO2) Brayton cycle. These cycles can reach nearly 50% thermal efficiencies in some cases and are much better suited to dry cooling than traditional Rankine cycles. Other major challenges to be studied include: Fuel

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fabrication – cladding will be an issue for long-term operations, but may be mitigated with venting (including sintered filters to allow noble gases to escape, but retain any radionuclides; Physical security design and operations for reactor and for grid; Dry cooling options; and Cyber security (especially for grid access problems).

Integrated Safety, Operations, Security, and Safeguards

Some of the major concerns with the previous reactor designs (Candlestick and Traveling Wave) seem to have resulted from the traditional design process. The engineering and safety aspects of the reactor were emphasized at the beginning of the design work, while security and safeguards were not necessarily designed at the beginning stages. We propose that these issues can be overcome with a more integrated approach to the design of the system. Research addressing how to best design nuclear facilities to ensure that safety, safeguards, and security are adequately considered before construction begins has been ongoing for decades (3S By Design). Sandia has been an active participant in this work and developed a handbook to formalize a Concurrent Engineering methodology to include 3S as well as operational aspects into the design activities for a nuclear facility [Middleton and Mendez, 2013]. Using this approach to design and develop the reactor and the associated grid could greatly mitigate the problems associated with the work that was previously attempted. One of the major benefits of such a process is the elimination of retrofitting a plant after it is constructed. This process will play a key role in successfully developing a safe, secure, autonomous, economical nuclear cartridge.

Smart Microgrids

Current smart grid technology allows highly reliable control of energy transfer and managing diverse energy sources to include the reactor and renewable sources. The SMR would be connected to a grid that is used to route electricity to the regions needed. It could also be used to aid in control of the reactor itself. If demand changes, a signal would be sent to the reactor which would either insert the control rods (to decrease power) or withdraw the control rods (to increase power). One area of interest is determining the maximum power level for which automated grid control is feasible. Monitoring of the grid, along with machine learning algorithms, could be used to detect grid hacking attempts and report to the international monitor for intervention based on pre-determined security protocols.

In conclusion, we are proposing a conceptual study to design and develop an integrated system that combines a nuclear cartridge with an advanced power conversion sub-system, a smart grid, and potentially renewables energy source to provide economic, reliable, safe and secure power to remote areas and small towns that complies with all international standards on safety, security, and nuclear nonproliferation.

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