RADIANT

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REVISION LOG

Rev.	Change Summary
1.0	Initial Release

CONTENTS

FIGURES

REFERENCES

[1] L. M. Beck and L. F. Pincock, "High Temperature Gas-Cooled Reactors: Lessons Learned Applicable to the Next Generation Nuclear Plant," INL Next Generation Nuclear Plant Project, 2011.

1 INTRODUCTION

Radiant Industries, Inc. is seeking a commercial license for the Kaleidos microreactor. This Regulatory Engagement Plan details Radiant's pre-application process by identifying:

- Unique design features
- Potential regulatory challenges
- Topics for technical discussions
- The anticipated licensing path
- A schedule of proposed activities

Radiant seeks input, feedback, and guidance in response to the information outlined in this plan in order to inform decisions and actions during the pre-application process, culminating in the submissions of a license application. Radiant understands the value of regulation and seeks to build a strong relationship.

For the first unit, Radiant plans to complete all the analysis, testing, documentation, and communications required within the existing framework. During this initial license application, we expect to identify areas for modernization in the process that would be beneficial in future applications and will share these observations with the NRC. Especially valuable will be guidance on the interpretation of regulations that were written for existing design and how those regulations should be applied to advanced reactors to achieve safer or more robust systems.

1.1 Communication

To establish accountability and facilitate communication, the main point of contact will be:

Chanson Yang

chanson@radiantnuclear.com

1921 Maple St. El Segundo, CA 90245

While the point of contact should be cognizant of all correspondence related to licensing, it is not a requirement that communication to or from Radiant go through the point of contact. Additional points of contact will be provided directly to the regulatory project manager.

2 BUSINESS MODEL

Details of Radiant's business model are provided to communicate the motivation behind design and operational decisions; each of these decisions are carefully formulated to meet an important customer requirement while complying with the intent of the regulation.

2.1 Size and Packaging

Kaleidos is a ~1 MWe microreactor designed to fit within the physical envelope of a single shipping container, making it road, rail, air and sea transportable; by using a conventional shipping container, the need for specialized equipment or handling procedures is eliminated.

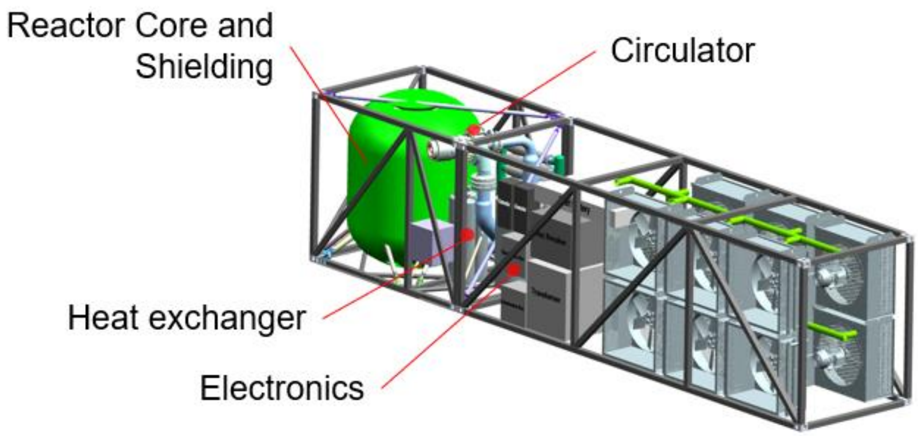


Figure 1 Graphical representation of a Kaleidos microreactor

2.2 Production

Kaleidos microreactors will be produced on an assembly line in a centralized manufacturing facility, eliminating the variation and defects associated with one-off projects while lowering unit cost and lead time. Microreactors will be built to meet a target production rate and will be insulated from changes in demand; this reduces staff and supply chain fluctuations which in turn reduces the associated defects, cost, and schedule impacts. This model may result in the temporary storage of completed microreactors.

Fueling and Zero Power Critical (ZPC) testing will occur at the factory, allowing for demonstration of functionality and defect screening in a controlled environment, prior to deployment at a site. Screening defects prior to shipping improves safety of that system during shipping, arrival at customer site, and prior to on-site ITAACs completion. A ZPC test at factory acceptance removes uncertainty in multiplication factor of the as-built product.

2.3 Operations

Kaleidos microreactors will enter the operational fleet upon activation; remote monitoring of all microreactors from a central control room will allow data collection and trend analysis, yielding improved levels of safety. By operating numerous units of the same design, data across multiple microreactors will be collected and allow for design/operating limits to be validated against a broad and diverse sample, yielding tighter control and greater confidence in operating limits. Live monitoring during operations is an improvement that could both improve safety and meet the intent of modernization efforts. Observations that result in a software update or process change can be immediately pushed out to the entire fleet.

2.4 Potential Applications

Kaleidos micoreactors are proposed as replacements for diesel generators, providing power to areas that are not being served by a traditional grid; these may be temporary applications due to disruption of existing infrastructure, such as regions struck by environmental disaster, or permanent installations in areas where connection to municipal power is impractical, such as remote regions in Alaska.

In the case of temporary installations, the transportability of Kaleidos microreactors and ability to quickly activate and enter operations would substantially reduce downtime, especially important for instances of disaster relief and humanitarian aid. As these are emergent conditions that cannot be forecasted, Radiant plans for Kaleidos microreactors to be tolerant to a conservative set of environmental conditions to avoid the need to do a unique site assessment.

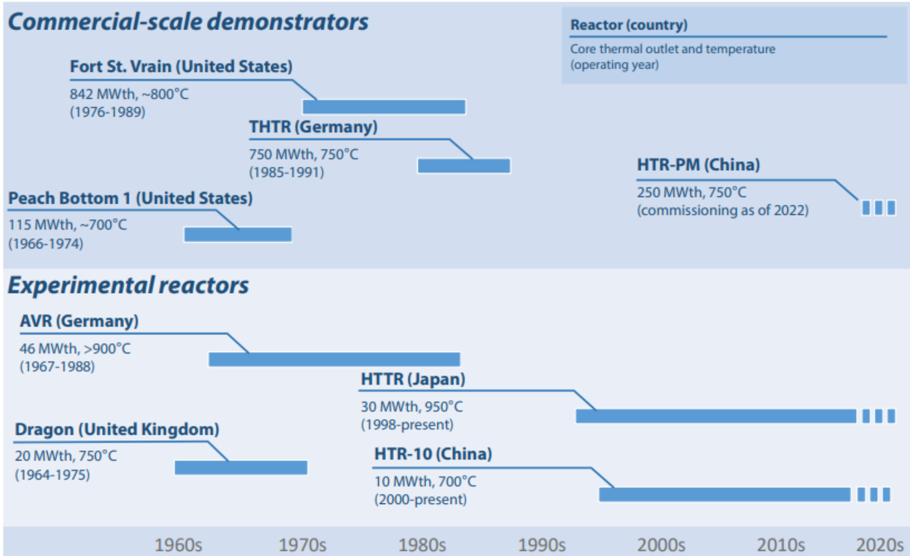
When used as primary power generation at installations in remote locations, the lack of recurring fueling operations compared to diesel generators yields significant cost, logistical, and environmental benefits. By performing zero power testing at the manufacturing facility, Radiant can assure that Kaleidos microreactors will successfully activate and operate without issue once they arrive, avoiding complex in-field repairs. Remote monitoring capabilities will enable quick responses to observations, eliminating a reliance on personnel deployed at these sites.

Radiant has numerous other proposed applications for Kaleidos outside of those mentioned above, especially for utility power providers:

- In peak-shaving applications to provide base power generation, allowing adjustable output power facilities to operate at lower utilization with higher margin.
- As supplemental capacity for weather-dependent renewable sources to reduce variability.
- For local operation in high-consumption areas to improve grid stability and reduce transmission loss.

3 DESIGN/UNIQUE FEATURES

Radiant utilizes proven technology in designing the Kaleidos microreactor, a high temperature gas reactor (HTGR) consisting of a prismatic graphite core that is loaded with compacts of TRISO fuel, moderated with zirconium hydride and uses helium as the primary coolant. As HTGRs have been built and operated for more than 50 years [1], Radiant draws upon existing qualification tests and data to avoid the uncertainty and risk inherent in developing low technology readiness level concepts.



Source: Beck and Pincock, 2011; CNNC, 2021.

Figure 2 History of HTGR plants

The Kaleidos microreactor is unique in how it will be deployed and operated; the proposed size and transportability of the microreactor are objectively ordinary but unlock unique considerations when taken in combination, such as unit-construction packaging, remote operations, and flexible site selection.

In addition to these unique physical and operational considerations, Radiant's goal to deliver an inherently safe and robust product led us to invest heavily in our simulation and test infrastructure. As we progress through test campaigns, we will utilize internally developed software known as SimEngine that hosts our digital twin, which can be configured to represent any combination of physical and virtual hardware; these products will be used to qualify our controls software in accordance with NQA-1. Through continuous integration testing, the uncertainty of the inputs can be reduced significantly; furthermore, changes to either those inputs or the digital twin itself will automatically queue and re-run tests to identify any variation in the outputs and results.

Central to the setup of SimEngine and the creation of the digital twin has been a focus to ensure consistency and reproducibility, so that a given test configuration with the same inputs and initial conditions will produce the same outputs on different hosts. In doing so, our goal was to minimize the noise contributed by the operator or test hardware, which will allow increased regulatory efficiency as tools can be shared more readily between Radiant and the NRC.

3.1 Unit Construction

Kaleidos microreactors will be built, shipped and operated as complete utilization facilities. This will eliminate the majority of the construction work typically associated with reactor builds and take further advantage of the benefits of manufacturing in a production facility. Site activation will also be greatly simplified: prior to shipping, an acceptance test can be performed at the factory and no further assembly or construction will be required when the microreactors arrive at their operating site. Post shipment, transportation vibration records can be reviewed to ensure that the unit experienced only expected and analyzed loads during transport.

3.2 Remote Operations

The reduced size of Kaleidos microreactors eliminates many of the traditional operations associated with nuclear reactors, such as changes in power setpoint, refueling and on-line maintenance; these operations are either automated, performed at a central manufacturing facility, or made obsolete. This change requires a new model of operations, one in which numerous microreactors at multiple sites are managed remotely. Radiant is planning a concept in which microreactors are remotely monitored, utilizing increased connectivity and safety-automation to augment the capacity of a centralized control room. To support this approach, emphasis was placed on inherent safety wherever possible, designing a component or system that defaults to a safe condition and does not rely on instrumentation or controls that may fail. The table below summarizes the common safety concerns and the type of control implemented in comparison to traditional reactor designs.

Safety Concern	**LWR Control**	**Kaleidos Control**
Heat Management	Active (coolant)	Passive (radiant)
Radioactive Coolant	Active (containment & monitoring)	Inherent (Helium gas)
Corrosion	Active (inspection)	Inherent (He is noncorrosive)
Reactivity Control	Active (rods)	Active (drums)
Fuel Containment	Passive (rods with cladding)	Inherent (TRISO)

If connectivity to a microreactor is lost or any unsafe condition occurs, safety-automation ensures that the system shuts down without the need for any external intervention. Radiant believes that increasing the amount and portability of reactor telemetry at this scale will dramatically modernize operations and increase safety in ways that were previously not possible, such as through the use of machine learning on incoming data to quickly identify outliers and by providing real-time access to a greater number of NRC users. Integral to this approach will be the use of software to create an inherently safe design by automating decisions based on test data and analysis, with trained operators supervising and intervening in the event of unexpected scenarios.

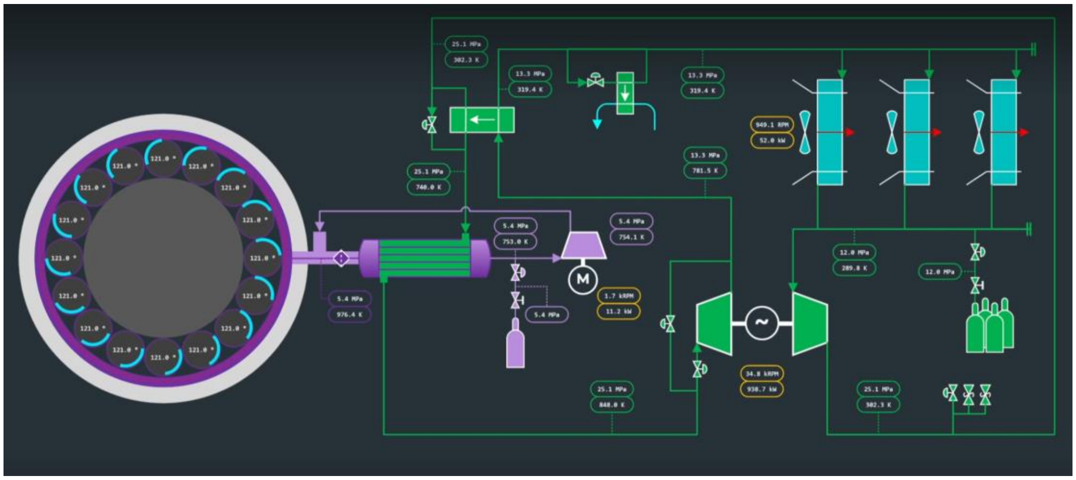


Figure 3 Visualization of Kaleidos operating status

3.3 Site Selection

Radiant expects to produce on the order of tens to hundreds of Kaleidos microreactors; these quantities—along with temporary installations and rapid response applications—require an efficient approach to addressing the environmental requirements and concerns regarding site selection. Each microreactor is built to the same specification while the unique characteristics for the final site are not known and cannot be considered ahead of time; therefore, Radiant is designing Kaleidos to be tolerant of and compatible with a wide variety of potential sites.

4 REGULATORY CHALLENGES

Select topics with potential regulatory hurdles are highlighted in the sections below; Radiant expects to seek guidance from the NRC on these topics and will provide more detail and potential solutions in future exchanges.

4.1 Zero Power Testing

Testing must occur at the factory to characterize the reactor, determine control drum angles, and validate that the build conforms with requirements; any nonconformances that do occur can be identified and rectified prior to shipping, avoiding risk in transport and operation. Radiant anticipates challenges with the lead time for advanced notifications ahead of fuel loading and reactor testing.

Radiant anticipates unique licensing approaches to support the building, fueling and testing of multiple microreactors at the manufacturing facility, potentially seeking additional, separate licenses for specific portions of the process, similar to the ideas proposed in ML23200A301 (Presentation Slides - Periodic Advanced Reactor Stakeholder Meeting 07/20/2023).

4.2 Transportation

Microreactors will be transported to the site of operations after initial testing at the factory; Radiant anticipates challenges with 10 CFR Chapter I Part 71 which specifies testing for containers used in transporting radioactive material.

Radiant plans to pursue the 71.41(c) pathway, electing alternate test criteria, as described in ML21235A418 (Micro-reactors Licensing Strategies).

4.3 Site Selection

As noted in section 2.2, microreactors will be built at a steady rate and may be temporarily stored in inventory until ordered by a customer, therefore, the lead time between site selection and deployment will be truncated from a period of years to weeks or even days. Radiant anticipates challenges with the standard review time associated with licensing events (early site permitting, construction license, combined operating license).

Radiant plans to discuss with the NRC the feasibility of obtaining a construction permit for a “theoretical site” that encompasses the worst-case conditions of all expected future sites; to streamline the process, future applications for construction permits would be compared to the existing permit to verify that all parameters fall within the values of the originally issued permit.

4.4 Onsite Personnel

Kaleidos microreactors are designed to be monitored and controlled by operators who are located at a geographically distinct and separate location from the installation site; while onsite security will be present to control physical access, no control or operation support buildings will be erected alongside the deployed microreactor. Radiant anticipates challenges with 10 CFR Chapter I Part 50 which requires a minimum number of operators at an onsite control room.

Radiant believes the intent of the requirement is to provide a specific level of oversight and monitoring, which will be achieved by redundant and secure connectivity between microreactors and numerous operators at a central control room. Additionally, given the fact that operator mistakes have been a large contributor to past accidents, Radiant envisions inherent software safety features beyond what is required by the regulation to provide safety beyond the level intended by the requirements in Part 50.

5 LICENSING PATH

Radiant is considering multiple licensing pathways, driven by the following key considerations:

- Work that must be repeated for each microreactor should be standardized and minimized
- Fueling and testing must occur at the manufacturing facility
- Approval should cover as many geographical sites as practicable

Multiple licensing paths are illustrated below and will be explored further to determine which path will best fit Radiant’s particular use case.

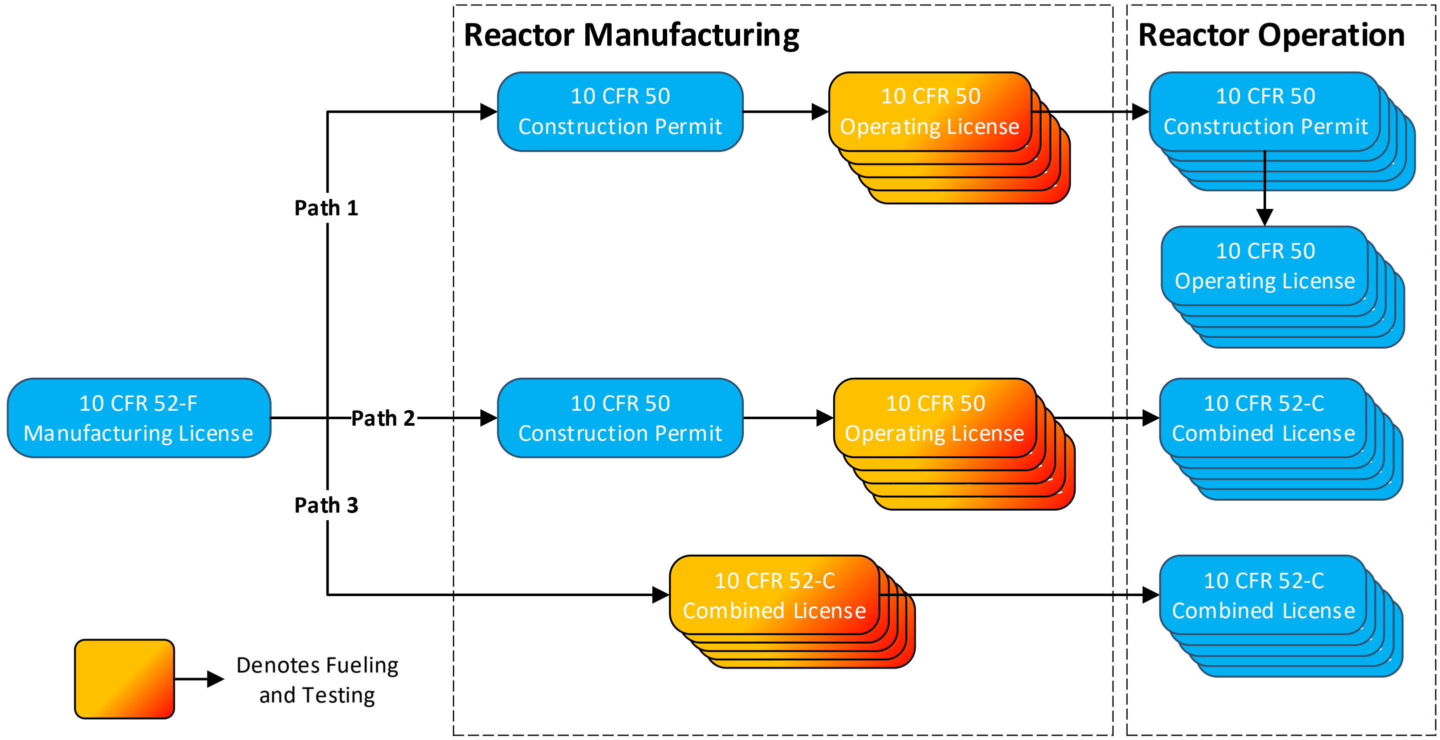


Figure 4 Potential Kaleidos licensing paths for five microreactors

6 TESTING

Radiant embraces an incremental validation approach that relies heavily on building and testing hardware; frequent test campaigns that verify engineering designs at component and subassembly levels help buy down risk long before a complete microreactor is manufactured. This results in a shortened schedule with high confidence.

Below are the test events planned to support DOME; data generated from these events may also contribute content to our license application.

- Jan 2024 – Reactor Pressure Vessel Hydrostatic Test
  - Validation of the pressure vessel design and build process, occurring prior to reactor assembly, gating the electrically heated passive cooling demonstration test and safeguards against a potential issue being passed along and affecting schedule.
- Apr 2024 – Electrically Heated Passive Cooling Demonstration Test
  - Test of the assembled, as-built reactor to validate the models and simulations used in designing the reactor. This also serves as an opportunity to gather data which is used to check assumptions and refine analysis tools.
- Oct 2025 – Assembly Validation Testing for Demonstration Unit
  - Build of the demo unit will be a pathfinder to improve work instructions and procedures and inform changes for production to improve quality and increase efficiency. Interactions across all assemblies and subsystems can be observed with physical hardware.
- Oct 2025 – Transportation of Assembled Unit

   - Transportation loads and concepts of operation are verified and modified as needed. Special tooling or handling fixtures are tested or designed if needed.
- Oct 2025 to Jan 2026 – Fueling
   - Material handling procedures are executed in a controlled environment.
- Jan 2026 – DOME Testing and Criticality
   - Approach to Critical - Proof of design and high-fidelity data collection, expected reactivity insertion for criticality
   - Reactor heatup – Increases power, proof of safe management of reactivity coefficients
   - Power increase – Reaches full power, coordinated with heat removal by secondary loop
   - Load following - validates controls, software and procedures prior to certification of a commercial unit.
   - Passive cooling – simulated helium pump failure demonstrates passive cooling, thermal modeling.

7 SCHEDULE

A Kaleidos demonstration unit will be built and tested as part of the Demonstration of Microreactor Experiments (DOME), currently targeted for 2026. Radiant anticipates using this experiment and the data gathered from it to both inform and validate the design of the microreactor. As a result of this early demonstration and verification, Radiant anticipates completing the license application on an accelerated timeline; below is a graphical representation of test milestones and a sampling of topics for further discussion. A notional schedule with greater detail will be delivered in conjunction with future meetings to inform staffing plans and align support expectations; when selecting topics to include in this schedule, Radiant will take guidance from ML21145A106 (DRAFT Pre-application Engagement to Optimize Advanced Reactors Application Reviews).

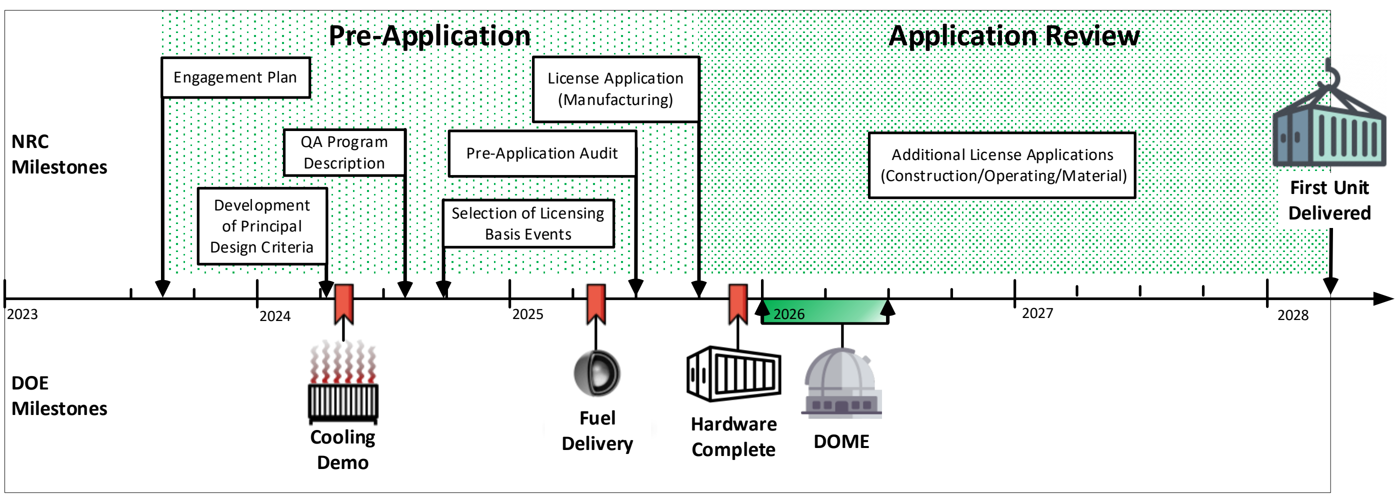


Figure 5 Kaleidos test events and select regulatory milestones

8 TECHNICAL EXCHANGES

The following items cover the technical information that Radiant plans to discuss during the pre-application phase to facilitate understanding with the NRC prior to submission of a formal application.

8.1 Meetings

Radiant anticipates engaging with the NRC on a number of topics to support the license application. The following is a list of potential areas for discussion:

- Application Schedule
- Licensing Path
- Code Interpretation and Compliance
- Gap Analysis
- Test Plans
- Digital Twin
- Risk/Technology
- Analysis Methods

Radiant will also conduct a series of proprietary, internal reviews to coincide with the design maturity and build schedule of the Kaleidos demonstration unit. Where helpful in demonstrating compliance to regulatory requirements or otherwise beneficial in communicating information, Radiant will coordinate with NRC staff to attend these reviews.

8.2 White Papers

Due to the novel features utilized by the Kaleidos microreactor to improve safety and increase operational efficiency, Radiant may submit white papers to explain how these features achieve the underlying intent of the regulatory framework. The list of potential topics for white papers include:

- Reactor Design
  - Primary and secondary coolant loops
  - Reactivity control and redundancy
- Operational Plans
  - Zero power factory testing
  - Remote monitoring and control
- Analysis and Assumptions
  - Worst-case siting conditions
  - Digital twin and simulation
- Regulatory Compliance
  - Principal design criteria
  - Consolidation of multiple licenses
  - Exceptions

The above list is not exhaustive and topics may be added, removed or revised throughout the preapplication phase.