OKLO

DG-1353 Pilot

Submittal to Support NRC Development and Implementation of DG-1353, A Guidance to Risk-Inform Application Development and Contents Including Event Selection and SSC Classification

September 2018

Oklo Inc., [redacted]

PILOT APPLICATION FOR DG-1353 EXECUTIVE SUMMARY

Introduction

This application structure is being submitted as a pilot for draft regulatory guide (DG)-1353, "Guidance For A Technology-Inclusive, Risk-Informed, and Performance-Based Approach to Inform the Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors." In public meetings, NRC staff issued a call for designers to pilot the upcoming draft guidance. Oklo is offering this pilot of the guidance as an example for NRC staff in evaluation of the possible benefits, drawbacks, or other impacts of a proposed guidance. The goal is not to show the impacts of the guidance in a final form, but for illustrative purposes in a possible application structure how the guidance may be used for a particular design, and further how the implications of its use might affect a submittal to the NRC on a relatively holistic basis. Although the Draft Guidance intends to reference a future NEI report, for the purposes of the preparation of this report, the Licensing Modernization Project report "Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis Development," Revision L, issued May 25, 2018 was used.

The DG-1353 provides an alternative means for performing the necessary tasks of analyzing licensing basis events and for assessing safety-relation of structures, systems, and components (SSCs) as well as defense-in-depth. The guidance is part of a broader transformation of the NRC to more effectively regulate potential new technologies, which is described in SECY-18-0060, "Achieving Modern Risk-Informed Regulation," and other documents.

Of particular concern to NRC staff is ensuring that the level of detail submitted and reviewed in regulatory review is appropriate to that required to make decisions, especially safety decisions on the design in question. Excessive detail would slow review, and utilize unnecessary federal resources, while too little detail would have the same effect, due to the need for the NRC to ask questions on detail not provided but needed to reach a decision.

It is expected that the proposed guidance could provide a framework for both applicants and the NRC to have more regulatory certainty on level of detail required for applications. The DG-1353 framework provides a baseline for what SSCs are safety-related or important to safety, and therefore a relative basis for application content as far as level of information necessary and appropriate for topics required by regulation to be addressed in an application. This pilot submittal in particular may provide one perspective on how analysis of licensing basis events, safety-relation and importance to safety of structures, systems, and components, and resulting evidence of defense-in-depth may affect level of detail to meet existing regulatory requirements in a possible application. The structure of this pilot submittal was developed directly from regulatory requirements for application structure. These requirements are outlined in Title 10 to the Code of Federal Regulations (10 CFR) sections as appropriate for different approval, certification, permits, or licensing pathways. For example, for a standard design certification, rules for contents of applications are specified in 10 CFR 52.46 and 52.47. For a standard design approval, rules for contents of applications is given in 10 CFR 52.136 and 10 CFR 52.137. For a combined license (COL) application, rules for contents of applications are given in 10 CFR 52.77, 52.79, and 52.80. In the interest of holistic application of the concepts covered in the DG-1353, the requirements for a COL application were followed.

Structure

The NRC does not require applicants to follow a certain structure for applications. The application structure which has been used for prior operating commercial reactors, that is, conventional light water reactors, was developed after several light water reactors had been designed, approved by the regulatory body, and built and operated. It was based on light water reactors and is only appropriate to large degree to light water reactors (LWRs). Therefore, it is in the interest of the NRC and applicants seeking to submit an application for a non-LWR application not to follow the existing voluntary guidance for LWRs while meeting all existing regulatory requirements and/or intent as given in the relevant sections of the code of federal regulations. The structure submitted here was developed in an interactive way with NRC staff. It is not considered final but potentially representative of a way to clearly illustrate application relevance with regulatory requirements, even for a non-LWR.

Content

This pilot submittal takes the form as laid out in the regulations for requirements for combined licenses (10 CFR 52.77, 10 CFR 52.79, and 10 CFR 52.80). These regulations have relatively few LWR-specific requirements, as opposed to the correlating guidance for applicants and the regulator; Regulatory Guide (RG) 1.206, "Combined License Applications for Nuclear Power Plants (LWR Edition)" and NUREG-0800, "Standard Review Plan for the Review of Safety Analysis Reports for Nuclear Power Plants: LWR Edition," respectively. Additionally, RG 1.70, "Standard Format and Content of Safety Analysis Reports for Nuclear Power Plants (LWR Edition)," was also used generally to inform this proposal and guidance for review of safety analysis reports may also be useful.

Following 10 CFR 52.77, 10 CFR 52.79, and 10 CFR 52.80 effectively gives five primary parts, or the final safety analysis report + 4 separate categories. These five primary parts are:

- 10 CFR 50.33 Requirements (from 10 CFR 52.77: "Contents of applications; general information);
- Final Safety Analysis Report Requirements (from 10 CFR 52.79: "Contents of applications; technical information in final safety analysis report");
- Proposed Inspection, Tests, Analysis and Acceptance Criteria (from 10 CFR 52.80: "Contents of Applications; additional technical information," part a);
- The Environmental Report (from 10 CFR 52.80: "Contents of Applications; additional technical information," part b); and
- The Requirements from 50.54(hh)(2) for Loss of Large Area of Plant (from 10 CFR 52.80: "Contents of Applications; additional technical information," part d).

Two other high-level parts may be added to this structure or separated out from the FSAR requirements section to mimic past application structures: Technical Specifications (which will largely refer to the FSAR Section 23) and Departures/Exemptions. However, both are outside the scope of this pilot. The focus of effort for this pilot submittal is the content of the FSAR. The level of detail required in each part and each section of each part is informed by the

principles contained in DG-1353. Where detail in a part or section is out of the scope of this pilot, it is indicated.

By using this format, the tie of the submittal to the regulations for each section or part is clear. In general, the order of the FSAR sections in this report directly follow the order of the regulation, with the exception of sections specifically noted as being applicable to light water reactors.

For NRC staff review, there is also guidance in 52.81, "Standards for review of applications." While 52.81 refers generally to 10 CFR Parts 20, 50, 51, 54, 55, 73, and 100, it provides a non-guidance related standard for review of applications and must be an option and indeed be fundamental as the existing critical regulation governing review of applications regardless of structure.

Scope and Information Types

This pilot submittal is scoped to only include non-safeguards information. Additionally, it is scoped to analyze internal events for an operating plant. Other sections may be noted as outside the scope of this pilot, as noted within the relevant section. Some portions may note areas of analysis yet to be completed. It is the intent that the level of detail for sections within the scope, with the provision that only internal events are analyzed, is near to the amount of information required for an actual application.

The goal was to allow for as much as possible to be made public, so there are frequently only portions of single sentences withheld. Portions considered to be withheld per reasons given in 10 CFR 2.390 are marked within brackets "{" at the beginning of the portion, and "}" at the conclusion of the portion. Any figures, tables, or footnotes included in line with text within brackets is to be treated with the same characterization. Immediately following each withheld portion, the reasoning is given based on reasons within the affidavit, within section 4(c). The reasons are given between (i) and (xi) within the affidavit section 4(c). Because of this, the shorthand within the rationale immediately following each withheld section will refer to which items (i)-(xi) are the reasons for the information to be withheld because trade secret and commercial or financial information and privileged or confidential. Additionally, pages containing such portions are marked at the top of the page with a box. Portions of export-controlled information, per definition by 10 CFR 810, are also within brackets, and following each bracket containing export controlled information, a marking within brackets is provided as "{eci}," which is shorthand for "export controlled information."

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I. Company Information and Financial Requirements

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1 PURPOSE AND SCOPE

Title 10 to the Code of Federal Regulations (10 CFR) Section 50.77, "Contents of applications; general information," requires that 10 CFR 50.33, "Contents of applications; general information," be met. Section 50.33 to 10 CFR requires general company information and financial information.

The purpose of this section is to include relevant information as required by 10 CFR 50.33. Information pertaining to 10 CFR Part 30, "Rules of general applicability to domestic licensing of byproduct material," 10 CFR Part 40, "Domestic licensing of source material," and 10 CFR Part 70, "Domestic licensing of special nuclear material," is not discussed in this section. Additionally, information related to the requirements of 10 CFR 50.33(f), 10 CFR 50.33(i), and 10 CFR 50.33(j) is excluded from this document. Paragraph h to 10 CFR 50.33 is excluded because it likely does not apply to the Oklo design.

2 GENERAL APPLICANT INFORMATION

This section satisfies 10 CFR 50.33(a), 10 CFR 50.33(b), 10 CFR 50.33(c), and 10 CFR 50.33(d) requirements.

The applicant is Oklo Inc. (Oklo). Oklo is located at 230 E. Caribbean Dr., Sunnyvale, CA 94089. Oklo is a privately funded company focused on commercialization of its compact fast reactor design. This unique design utilizes well-known materials and commercial-grade components to manage design uncertainties and expedite commercialization.

Oklo is incorporated in the state of Delaware with headquarters in Sunnyvale, CA. The principal officers and their names, addresses, and citizenships are listed:

Jacob DeWitte	Caroline Cochran
CEO	COO
230 E. Caribbean Dr.	230 E. Caribbean Dr.
Sunnyvale, CA	Sunnyvale, CA
U.S. Citizen	U.S. Citizen

Oklo is an entirely privately funded company, committed to bringing the reactor design described here to market during over 5 years in development. Oklo was incorporated in 2013, [redacted]}{(iii), (iv), (ix)-(xi)} and is working with multiple national laboratories. The company anticipates funding the proposed activity as well as completing the remaining steps in commercialization, including design and licensing activities, with additional rounds of private financing.

Oklo has had successful funding rounds including dedicated investors who are committed to Oklo's mission and to rapidly bringing this technology to the commercial market. It is due to the small size and the simplicity of the Oklo reactor that private investors are able to fund design and construction. Oklo's board of directors sets milestones and oversees company progress. The chair of the Oklo board is also President of YCombinator, which has a portfolio of companies worth over $100 billion dollars, and brings this experience and insight to Oklo's management team. To date, Oklo has been committed and has excelled at meeting milestones which has been corroborated through investor due diligence.

Oklo has won the following awards: the top MIT team at the MIT Clean Energy Prize (2013), the winner of the energy track at the MIT 100k (2013), finalist at MassChallenge (2013), winner of the MassChallenge Gold Award (2013), and acceptance into the selective accelerator YCombinator (2014). Oklo was also featured in a Harvard Business School case (2015) and in a documentary about advanced nuclear, The New Fire (2018), in addition to numerous press articles over the years since its launch in 2013. Oklo has received three Gateway for Accelerated Innovation in Nuclear (GAIN) vouchers, totaling over $1 million in value.

Oklo has several currently interested customers as well as a well-developed market strategy. Detailed market studies and projections have been verified through investor due diligence. In addition, Oklo has been the recipient of awards to work formally with engaged markets including winning the Alaska Center for Microgrid Technologies Commercialization competition award from the Alaska Center for Energy and Power. [redacted]

[redacted] {(iii), (iv), (ix)-(xi)}

Oklo is majority owned by U.S. investors and employees and currently employs only U.S. citizens. Oklo currently does not have any partnerships or foreign ownership interests that would affect export control requirements. The company has a well-developed export control policy in place that controls export-controlled information and requires each and every employee and contractor to comply with U.S. export laws and regulations to the full extent that such laws and regulations apply to the proposed activity. Oklo has been diligent to maintain all possibly export-controlled information properly over its more than 5 years in development.

2.0 Class of License Application

This section satisfies 10 CFR 50.33(e) requirements.

[redacted]

[redacted].}{(ii)-(iv), (vi), (ix)-(xi)}

Special nuclear material shall be in the form of reactor fuel and spent fuel, in accordance with limitations for storage and amounts required for reactor operation, as described in this pilot submittal. Byproduct, source, and special nuclear material shall be in the form of sealed neutron sources for reactor startup and sealed sources for reactor instrumentation, radiation monitoring equipment, calibration, and fission detectors in amounts as required. Following the 10 CFR 52.103(g) finding, byproduct, source, and special nuclear material in amounts as

required, without restriction to chemical or physical form, will be used for sample analysis, instrument and equipment calibration, or associated with radioactive apparatus or components.

2.1 Financial Qualification

This section is required by 10 CFR 50.33(f) but is excluded for this pilot submittal.

2.2 Radiological Emergency Response Plans

This section satisfies 10 CFR 50.33(g) requirements.

This document provides a preliminary draft of an emergency preparedness plan in Section 15. [redacted] }{(ii)-(iv), (vi), (ix)-(xi)}

2.3 Generation and Distribution of Electric Energy

This section is required by 10 CFR 50.33(i) but is excluded for this pilot submittal.

2.4 Defense Information

This section is required by 10 CFR 50.33(j) but is excluded for this document. This pilot submittal does not contain restricted data or other defense information.

2.5 Decommissioning Information

This section outlines the approach for satisfying 10 CFR 50.33(k) requirements. Paragraph k to 10 CFR 50.33 requires complies with 10 CFR 50.75, "Reporting and recordkeeping for decommissioning planning."

Paragraph c to 10 CFR 50.75 provides minimum amounts necessary for decommissioning funds. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

Before a company begins operation of a nuclear facility, it must establish or maintain a financial mechanism, such as a trust or guarantee, to ensure that there will be sufficient funds to pay for the decommissioning of its facility. There are many factors that affect decommissioning costs for the current nuclear fleet, but they usually range between $300-400 million [1]. Decommissioning may be the retirement process used for the first Oklo plants and will be the ultimate retirement process. The burden of decommissioning will be much smaller for Oklo than that of the current nuclear fleet due to Oklo's small size. [redacted] }{(ii)-(iv), (vi), (ix)-(xi)}

The decommissioning fund amount is calculated from the thermal power rating of the nuclear facility. In Oklo's case, that rating is significantly smaller than a large nuclear reactor. Therefore, it is likely that the necessary decommissioning fund will be much smaller or that the necessary funds may be secured through a bond or credit that is some fraction of the amount required for commercial nuclear reactors.

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II. Final Safety Analysis Report

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1 SITING INFORMATION

1.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(1) requires that "the final safety analysis report shall include the following information, at a level of information sufficient to enable the Commission to reach a final conclusion on all safety matters that must be resolved by the Commission before issuance of a combined license:

(i) The boundaries of the site;

(ii) The proposed general location of each facility on the site;

(iii) The seismic, meteorological, hydrologic, and geologic characteristics of the proposed site with appropriate consideration of the most severe of the natural phenomena that have been historically reported for the site and surrounding area and with sufficient margin for the limited accuracy, quantity, and time in which the historical data have been accumulated;

(iv) The location and description of any nearby industrial, military, or transportation facilities and routes;

(v) The existing and projected future population profile of the area surrounding the site;

(vi) A description and safety assessment of the site on which the facility is to be located. The assessment must contain an analysis and evaluation of the major structures, systems, and components of the facility that bear significantly on the acceptability of the site under the radiological consequence evaluation factors identified in paragraphs (a)(1)(vi)(A) and (a)(1)(vi)(B) of this section. In performing this assessment, an applicant shall assume a fission product release[1] from the core into the containment assuming that the facility is operated at the ultimate power level contemplated. The applicant shall perform an evaluation and analysis of the postulated fission product release, using the expected demonstrable containment leak rate and any fission product cleanup systems intended to mitigate the consequences of the accidents, together with applicable site characteristics, including site meteorology, to evaluate the offsite radiological consequences. Site characteristics must comply with part 100 of this chapter. The evaluation must determine that:

(A) An individual located at any point on the boundary of the exclusion area for any 2-hour period following the onset of the postulated fission product release, would not receive a radiation dose in excess of 25 rem 6 total effective dose equivalent (TEDE).

[1] The fission product release assumed for this evaluation should be based upon a major accident, hypothesized for purposes of site analysis or postulated from considerations of possible accidental events. These accidents have generally been assumed to result in substantial meltdown of the core with subsequent release into the containment of appreciable quantities of fission products.

(B) An individual located at any point on the outer boundary of the low population zone, who is exposed to the radioactive cloud resulting from the postulated fission product release (during the entire period of its passage) would not receive a radiation dose in excess of 25 rem TEDE"

The purpose of this section is to provide an initial description of the site of the Oklo plant. Ultimately, the purpose of this section is to provide "information sufficient to enable the Commission to reach a final conclusion on all safety matters that must be resolved by the Commission before issuance of a combined license," in other words, information which is not necessary to reach a conclusion on safety matters required to be resolved by the Commission prior to the issuance of a license will be minimized. By utilizing draft regulatory guide (DG)-1353, "Guidance For A Technology-Inclusive, Risk-Informed, and Performance-Based Approach to Inform the Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors," an alternative path for performing the necessary tasks of analyzing licensing basis events and for assessing safety-relation of structures, systems, and components (SSCs) as well as defense-in-depth is provided. This framework, then, can provide a baseline for what SSCs are safety-related or important to safety, and therefore a relative basis for application content as far as level of information necessary and appropriate for topics required by regulation to be addressed in an application.

1.0.1 Meteorological Considerations

Site-specific information is typically employed as part of performing offsite dose estimations. However, the atmospheric radionuclide dispersion calculation performed as part of the dose estimations for the Oklo reactor's design basis accident analysis (see Section 5) assumed exceptionally conservative weather conditions so as to bound the potential dose beyond the site boundary. As such, the meteorological information presented describes these bounding conditions, which will be conservative compared to any U.S. location-specific conditions. {

1.0.2 [redacted]

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

1.0.3 Hydrologic Considerations

Hydrologic characteristics of the site are important for characterization as part of the analysis to determine escape pathways of liquid effluents. As the Oklo plant does not employ any water-based cooling in the reactor system, power conversion system, or any auxiliary systems, no radioactive liquid effluents are generated and as such, hydrologic site impacts are minimal. As a result, information on site hydrologic characteristics is not included.

1.0.4 Seismic and Geologic Considerations

Additionally, the present pilot effort is currently only scoped to include internal events for a plant. As a result, site-specific information on seismic and geologic characteristics is not included for this pilot, but further seismic analysis will be performed.

1.1 Evaluation

1.1.1 Site Description

An Oklo plant includes only a single building on the site, which is described in Section 2.7.2. [redacted]

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

As no other buildings are present on the site, no adjacent building obstruction factors were incorporated into the radionuclide dispersion analysis that formed part of the dose calculation, which increases the conservatism of the analysis. Additionally, the size of the Oklo site building was modeled as negligible to minimize building wake effects or self-obstruction of the emitted plume, which reduces the dependence of the dose calculation on the actual building dimensions. Not including the building wake effects is another conservative assumption compared with historical light water reactor assumptions on dispersion. Historically, large light water reactors incorporated substantive dispersion factors on plumes, which result in reduced dose calculations. By neglecting any building effects or effects from natural artifacts, these calculations are more conservative than these calculations done for existing plants. Releases were assumed to be emitted at approximately ground level.

1.1.2 Conservative Atmospheric Dispersion Assumptions

Meteorological conditions for the dose calculation in Section 5 are selected to be the most bounding possible to provide the widest applicability while retaining conservatism. In practice, this means considering the atmospheric stability as Pasquill class F during the entire period of radiological release. The wind speed is taken as 1 m/s, the lowest possible value accepted by the

radiological release modeling tool employed[2]. No ground deposition is credited, with 100% of the plume reflecting off the ground and continuing to travel downwind. Plume meander is set to zero (no meander), as is plume rise.

[2] The tool used for the dose analysis here is the MELCOR Accident Consequence Code System, or MACCS.

2 DESCRIPTION AND ANALYSIS OF STRUCTURES, SYSTEMS, AND COMPONENTS

2.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(2) requires, in part:

> A description and analysis of the structures, systems, and components of the facility with emphasis upon performance requirements, the bases, with technical justification therefor, upon which these requirements have been established, and the evaluations required to show that safety functions will be accomplished...

The purpose of this section is to provide an overview of the structures, systems, and components (SSCs) that are part of the Oklo design.

[redacted] {(ii)-(iv), (vi), (ix)-(xi)} For this pilot, all SSCs are only described for normal operation.

Although no specific guidance is applied, Regulatory Guide 1.206, "Combined License Applications for Nuclear Power Plants,"[3] is used to partially inform the organization of this section.

[3] Specifically, the version issued in June of 2007 is used.

2.1 Reactor System

2.1.1 Summary Description

The reactor system is designed to generate heat that can be moved to the power conversion system by way of the heat transport system and the heat exchanger system. This section describes the design of the mechanical and nuclear components of the Oklo reactor system{, [redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]

[redacted]

[redacted]

Figure 2-1. [redacted]

[redacted]

[redacted]

[redacted]}{(i)-(xi)}{eci}

The thermal design for the Oklo plant provides adequate cooling for the fuel and the core components during steady-state, full-power conditions via the heat transport system. As the Oklo plant does not include a flowing coolant traveling through the core, many of the concerns of thermal and hydraulic behavior need not be considered (e.g., critical heat flux, flow velocities, coolant and moderator voids). [redacted]

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

The reactor uses various instrumentation systems to monitor core performance; neutron flux monitors, cell temperature sensors, and other instrumentation systems are used to provide the operating parameters, trips, and alarms. More information on instrumentation and control systems is provided in Section 2.5.

[redacted]

Table 2-1. [redacted]

[redacted]

}{(i)-(xi)}{eci}

2.1.2 Reactor Core System

2.1.2.1 Description of the Reactor Core System

The function of the reactor core system is to generate heat from nuclear fuel{ [redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]}{(i)-(xi)}{eci} Since the Oklo core operates at a very low burnup, little to no fission gas is expected.{

[redacted]

Figure 2-2. [redacted]

[redacted]

[redacted]

Figure 2-3. [redacted]

[redacted]

[redacted]}(i)-(xi)}(eci} Because each heat pipe is a sealed, independent heat transport device, the heat pipes offer redundant and reliable cooling, and together form the heat transport system that removes heat from the fuel. More information on the heat pipes is located in Section 2.2.

[redacted]

Table 2-2. [redacted]

[redacted]

}(i)-(xi)}(eci}

2.1.2.2 Design Bases of the Reactor Core System

[redacted]}(ii)-(iv), (vi), (ix)-(xi)}

Performance design bases during normal operation include the following:

- The reactor core system is not damaged during normal operation and anticipated operational occurrences,
- The reactor core system is designed to produce appropriate amounts of heat to be transferred to the power conversion system,
- The reactor core system retains fission products during all modes of operation,
- The reactor core system is designed to limit eutectic formations [redacted]}(i)-(xi)},
- The reactor core system is designed such that the net effect of the prompt inherent nuclear feedback characteristics compensates for a rapid increase in reactivity, and
- The reactor core system is designed such that power oscillations are suppressed.

2.1.2.3 Materials of the Reactor Core System

Supporting reactor structures are constructed using stainless steel, chosen for its low neutronic absorption in the fast spectrum, significant operating and irradiation experience, and strength at Oklo's operating conditions. [redacted]

[4] [redacted]

Table 2-3. [redacted]

[redacted]

}{(i)-(xi)}{eci}

For purposes of this report, the discussion of material characteristics is focused on the fuel, including the fuel-steel chemical interaction, as this is considered the bounding analysis.

2.1.2.3.1 Fuel Type

The reactor core system employs a metal fuel, a metal alloy{[redacted]}{(i)-(xi)}. Metal uranium alloy fuel has a long history of use in U.S. fast reactors, beginning with the Experimental Breeder Reactor I (EBR-I) in 1951 and employed most extensively in the Experimental Breeder Reactor II (EBR-II), which ceased operating in 1994 [2]. Over 130,000 metal fuel pins were irradiated in the experiments over decades [3].

The thermophysical properties of metal fuel provide favorable performance in fast reactor operating conditions [4]. [redacted]}{(i)-(xi)} The thermal conductivity of metal fuel is high, which helps to reduce peak fuel temperatures and preclude local hot spots. In addition, the low heat capacity limits the amount of stored heat in the fuel while operating at temperature, enabling easier cooling of the fuel when shutting down or progressing through an abnormal event. [redacted]

Table 2-4. [redacted]

[redacted]

}{(i)-(xi)}{eci}

2.1.2.3.2 Fission Gas Generation and Fuel Swell

During irradiation, fission gases form void pores in the fuel, which in turns causes metal fuel to swell. Once the fuel swells by approximately a third of its volume, the fission gas voids

interconnect and the fission gasses are released to the upper plenum, with very little additional swelling[5].

[redacted] {(i)-(xi)}{eci} The interconnection of the fission gas voids typically occurs at a burnup of 2-3 at.%, which means that at lower burnups, most fission gases are retained in the fuel [5], [6]. [redacted] }{(i)-(xi)}{eci}

2.1.2.3.3 Eutectic Formation Considerations

Although the melting (solidus) temperature for the fuel is high, [redacted] }{(i)-(xi)} a more relevant limit for the Oklo fuel [redacted] }{(i)-(xi)}{eci} arises from considerations relating to eutectic formations. Eutectic effects between steel and fuel have been analyzed at length, for instance for the Integral Fast Reactor project and were typically referred to as fuel-clad chemical interactions. [redacted] {(i)-(xi)}{eci} Effects caused by fuel-steel chemical interaction occur at elevated temperatures where interdiffusion occurs between the uranium component of the fuel and the stainless steel and begins to form a lower melting-point eutectic. [redacted] }{(i)-(xi)}{eci}

A correlation developed by Argonne National Laboratory (ANL) and applied to the safety analyses in Section 5 shows that this process begins around 720 C but proceeds very slowly at this temperature (< 0.01 μm/s), increasing exponentially with temperature until reaching a rate of 0.1 μm/s at 830 C [7]. This ANL correlation was developed using fuel at burnups which far exceed the burnup of the Oklo fuel, such that the application of the rate curve described by this correlation to the Oklo reactor is conservative. Lanthanide fission products and fuel alloying element redistribution enhance fuel-steel chemical interaction. These effects occur in high burnup fuel, so they are not expected to be relevant for the Oklo reactor.

2.1.2.4 Performance and Evaluation of the Reactor Core System

2.1.2.4.1 Fast Neutron Spectrum

The Oklo reactor operates as a fast spectrum reactor, where neutrons born at fission energies of 2-3 MeV slow down only to about 1 keV to 1 MeV. Fast spectrum reactors generally are less sensitive to material selection because more materials are transparent to neutrons at those energies than at the thermal energy range. [redacted] }{(i)-(xi)} Fast spectrum reactors also do not experience significant sensitivity to fission product poisoning effects, since most strong thermal-spectrum absorbers like xenon-135 have very small cross-sections at high energies. [redacted]

[5] Accordingly, metal fuels designed for reaching high burnups include enough volume to allow the fuel to swell to this degree before contacting its enclosure, which helps to limit the stress applied to the fuel enclosure by the fuel itself. The Oklo fuel is not designed for high burnup operation.

[redacted]

Figure 2-4. [redacted]

}{(i)-(xi)}{eci}

2.1.2.4.2 Core Power Distribution

[redacted] }{(i)-(xi)}{eci} Small fast reactor cores, like the Oklo core, operate with relatively low radial and axial power peaking factors compared to most other reactor types due in large part to the unusually long mean free path of fast neutrons in the core and the small size of the core. The use of heat pipes in the Oklo design contributes to the long mean free path in the Oklo core. The vapor in each heat pipe has a density on the order of 1×10^{-3} g/cm^3. In other words, the vapor is essentially seen as a void by neutrons, with a very small probability of collision.

[redacted] {(i)-(xi)} Since the total neutron cross-section decreases with increasing incident neutron energy, a faster spectrum contributes to a large mean free path. A large neutron mean free path reduces core power peaking, helps the core to react to transients in a unified manner, and limits susceptibility to localized effects.

[redacted]

[redacted] }{(i)-(xi)}{eci} The axial power distribution is nearly symmetric [redacted] }{(i)-(xi)}{eci} and nearly follows the idealized cosine shape often used as an approximation for axial power distributions in other reactor systems. [redacted]

[redacted]

Figure 2-5. [redacted]

}{(i)-(xi)}{eci} The axial power distribution is shown in Figure 2-6.

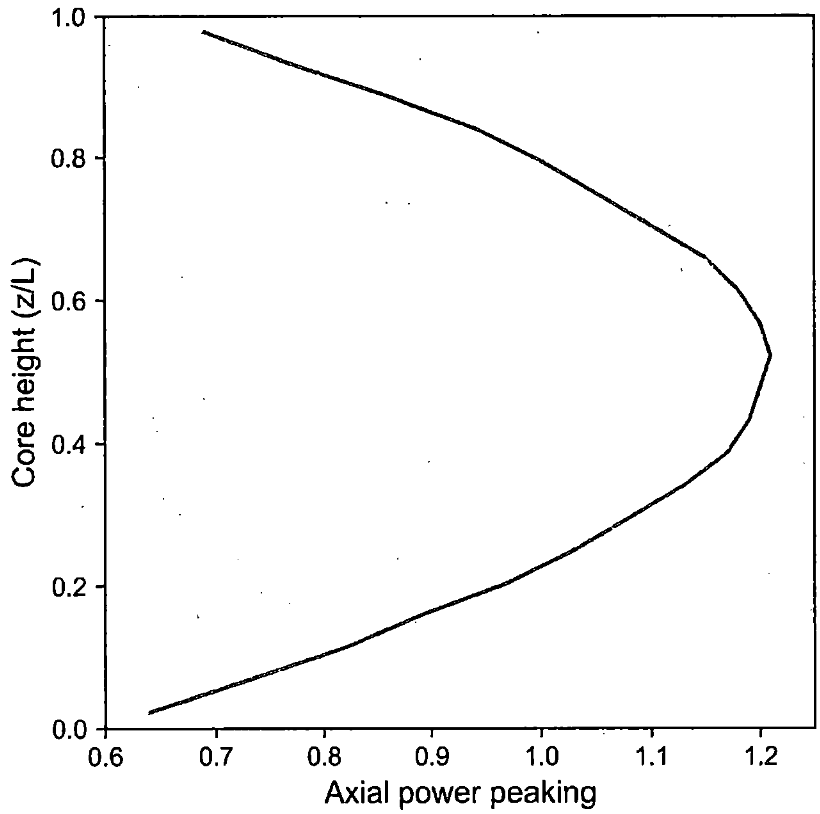

Figure 2-6. Axial power peaking profile in the peak reactor cell

2.1.2.4.3 Peak Fuel Temperature

[redacted] }{(i)-(xi)}{eci} A significant conservative assumption was made in the calculation of fuel temperature distributions: the thermal conductivity of the fuel was taken at one-half of its nominal value. This was done to account for the degradation in thermal conductivity associated with increasing porosity generated during irradiation, with 50% being the most conservative estimated degradation achievable [4]. [redacted] }{(i)-(xi)}{eci} Thus, using a thermal conductivity degradation factor of 50% introduces significant conservatism to the preliminary Oklo core design and analysis.

[redacted]

[redacted]

[redacted]

Figure 2-7. [redacted]

[redacted]

Figure 2-8. [redacted]

}{(i)-(xi)}{eci}

2.1.2.4.4 Inherent Feedback Mechanisms

The primary type of inherent feedback mechanism, which responds to operating condition changes in the Oklo reactor core, is the temperature feedback coefficient of reactivity. The Oklo core possesses negative temperature feedback coefficients of reactivity, which contribute to safe behavior during transient conditions. The feedback coefficient components of interest in the Oklo reactor are the fuel thermal expansion coefficient of reactivity, the fuel Doppler coefficient of reactivity, and the structural material thermal expansion coefficient of reactivity.

The fuel thermal expansion temperature coefficient of reactivity is the reactivity change in the core associated with the material expansion with increasing temperature of the metal fuel. The fuel Doppler coefficient is the reactivity change associated with the broadening of the fuel's reaction cross-sections with increased temperature. [redacted] {(i)-(xi)}{eci} The structural expansion coefficient is the largest

component of the net temperature coefficient of reactivity, primarily due to grid plate expansion. {

Table 2-5. [redacted]

[redacted]

}{(i)-(xi)}

Other temperature coefficients of reactivity can help contribute to the net reactivity coefficient. However, these additional components will operate on slightly slower timescales since they rely on heat generated in the fuel to be conducted radially outward through the core. Their contribution to the net coefficient is expected to be large and negative, so neglecting them for the present analysis introduces another large degree of conservatism.

2.1.2.4.5 Analytic Tools

Oklo is using various modeling and simulation codes to perform its core design and analysis. The following section describes these codes and their application, as summarized in Table 2-6. These codes are organized by function into the following sections: fuel behavior, reactor physics, and thermal analysis. Each code within a section contains a general overview of the code, a description of Oklo's use of the code, and some relevant verification or validation information.

Table 2-6. Summary of analytical tools used for Oklo core design

Computer code	Type	Application	Technique
BISON	Fuel Behavior	Model fuel and simulate fuel behavior during irradiation	Finite element-based code, solves fully-coupled 3D thermomechanics and species diffusion equations
SERPENT	Reactor Physics	Analyze physics and core modeling	3D continuous-energy Monte Carlo physics burnup calculation code for reactor analysis applications
MCNP	Reactor Physics	Analyze shielding; Benchmark other reactor physics codes	General purpose Monte Carlo particle transport code for wide range of applications by treating 3D configuration of materials in geometric cells
{[redacted]	[redacted]	[redacted]	[redacted] {(i)-(xi)}

ANSYS	Thermal	Analyze steady-state and transient temperature evolution of the core, heat conduction, thermal core design	2D and 3D thermal analysis
Flownex SE	Thermal	Model auxiliary cooling system performance and power conversion heat exchanger analysis	1D thermal fluid analysis

Fuel Behavior

Fuel behavior codes are used to evaluate how the fuel behaves during various reactor operating conditions. Fuel behavior analysis can be divided into two scenarios: steady-state and transients. The phenomenology of metal fuel behavior is considerably different than oxide fuel, and its safety characteristics are underpinned by its high thermal conductivity, low stored heat, expansion behavior during severe transients, and its resilience during irradiation. This simplifies the physics of interest, particularly at low burnups like those achieved in the Oklo design. Oklo's fuel performance code flow chart is shown in Figure 2-9.

BISON is a finite element-based nuclear fuel performance code applicable to a variety of fuel forms. BISON is built using the Idaho National Laboratory's (INL) Multiphysics Object-Oriented Simulation Environment (MOOSE). MOOSE is a parallel finite-element-based framework for solving systems of coupled non-linear partial differential equations. MOOSE supports the use of two and three-dimensional meshes and implicit time integration [8]. BISON solves the fully-coupled equations of thermomechanics and species diffusion for three-dimensional geometries. BISON is capable of analyzing a variety of fuel forms, including metal fuel.

Oklo uses BISON to model its fuel and simulate fuel behavior during irradiation. BISON provides the three-dimensional capabilities to model the unique geometry of the Oklo fuel design. The key parameters used in the Oklo fuel model include an input file that describes thermal and mechanical material models, boundary conditions, initial conditions, power history, and a mesh provided either directly in the input file or through a separate mesh file.

Quality of software developed by INL is tightly controlled using issue tracking, automatic testing or merge requests, and collaborative code review. BISON has been evaluated for NQA-1 compliance for R&D software [9], [10]. BISON, through MOOSE, is supported by more than 2000 tests. All new INL codes must be supported by testing. BISON includes verification tests for linear elasticity, large strain behavior, heat transfer, contact, and many other capabilities [11].

Oklo may also use stand-alone fuel failure models to support source term analyses. Some of these models are used in the SAS4A code. It is important to note that at temperatures below fuel melting, radionuclide release from failed metal fuel is dominated by those radionuclides that have migrated to the gap and fission gas plenum during irradiation. For low burnup fuel, the quantity of radionuclides that have migrated to the gap and plenum is comparatively small, so potential total releases are also comparatively small.

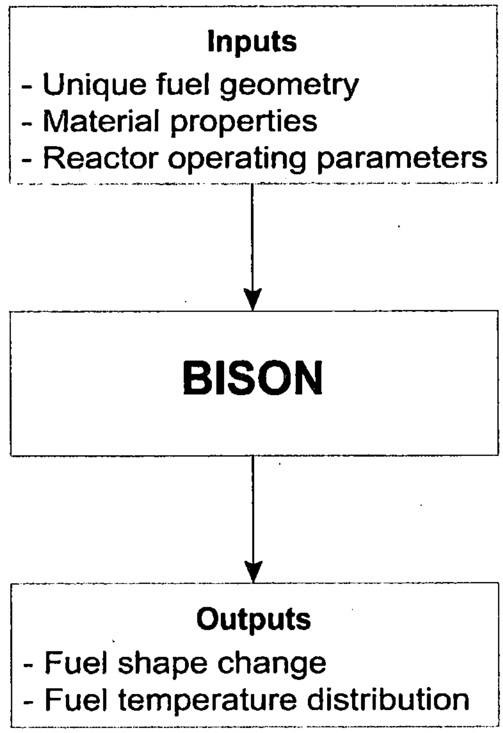

Figure 2-9. Fuel performance code flow chart

Reactor Physics Codes

Oklo uses reactor physics codes across two categories: steady-state and long timescale dynamics to evaluate physics changes in the core arising from burnup effects during operation, and short timescale kinetics to evaluate neutron flux distributions during transients.

Oklo predominantly uses high-fidelity, three-dimensional, continuous energy Monte Carlo neutron transport codes to evaluate its steady-state and long timescale dynamic core behavior. Such high-fidelity tools are not typically used in the design process for nuclear reactors due to the long simulation times required and are instead used for benchmarking and validation purposes of simplified tools. However, the small size and tightly-coupled neutronic behavior of the Oklo core enable the use of these benchmarking Monte Carlo codes for core design and analysis throughout its fuel cycle in a reasonable manner. The significant neutron streaming present in the core generally challenges the capabilities of deterministic codes, including conventional cross-section generation. However, these physics are readily captured via Monte Carlo methods.

Oklo models the short timescale kinetic behavior of the reactor using a point kinetics model. The point kinetics parameters of the core are generated using Monte Carlo tools. Point kinetics provide a good representation of a small, tightly-coupled system like the Oklo core, so using Monte Carlo tools to generate these parameters gives the greatest accuracy for a point-kinetics-based kinetics simulation. {

[redacted]

Figure 2-10. [redacted]

}{(i)-(xi)}{ec} Serpent is a three-dimensional, continuous-energy Monte Carlo reactor physics burnup calculation code specifically designed for reactor analysis applications. The standard output includes effective and infinite multiplication factors, point-kinetic parameters, effective delayed neutron fractions, and precursor group decay constants. User-defined tallies can be set up for calculating various integral reaction rates and spectral quantities, such as tallying power distributions throughout the core [12]. Serpent incorporates an internal burnup calculation capability that enables Serpent to be used to simulate fuel depletion as a completely integrated, stand-alone application. Extensive effort has been put into optimizing the calculation routines

and the code is capable of running detailed burnup calculations similar to deterministic codes within a reasonable calculation time. The overall running time can be further reduced by parallelization [13].

Oklo uses Serpent for reactor physics analysis and core design modeling. Serpent has the advantage of being a recently developed tool with faster processing times than other Monte Carlo tools. The input files are easy to use with the Oklo design, and the code does not require the significant amounts of pre- and post-processing traditionally associated with legacy tools.

For code validation, each Serpent update is checked by comparison to the general-purpose program Monte Carlo N-Particle (MCNP) code by running a standard set of assembly calculation problems. Effective multiplication factors and tallied reaction rates are within the statistical accuracy of the reference results when the same ACE libraries are used in the calculations. Validation against MCNP has also been carried out with equally good results for calculations involving individual nuclides, by comparing the flux spectra produced by the two codes.

MCNP is a general-purpose Monte Carlo particle transport code that can be used for neutron, photon, electron, or coupled neutron/photon/electron transport. Specific areas of application include, but are not limited to, radiation protection and dosimetry, radiation shielding, radiography, medical physics, nuclear criticality safety, detector design and analysis, reactor design, decontamination, and decommissioning. The code treats an arbitrary three-dimensional configuration of materials in geometric cells [14].

Oklo uses MCNP version 6.2 as a benchmarking tool. Although MCNP requires more processing time, MCNP has been the standard tool for 3D Monte Carlo neutron transport analysis for decades. Like Serpent, it is capable of three-dimensional modeling with highly complex geometric structures and employs the full-fidelity continuous energy representation of neutron cross-sections.

For code validation, the MCNP reference collection includes several verification and validation benchmark suites (over 60 suites each with multiple sets of verification problems). Los Alamos National Laboratory invests substantial effort to ensure that production releases of MCNP and MCNP data libraries have undergone rigorous testing, verification, and validation.

Oklo uses point kinetics to model short timescale transients. The small size, tightly-coupled neutronic behavior, and limited excess reactivity of the Oklo core enables the use of point kinetics as an accurate means to analyze transient behavior. There is very little spatial variation in flux or power during transients. [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]}(i)-(xi)}(eci}

Thermal Analysis

The strong thermal coupling of the core enables Oklo to use three-dimensional heat conduction codes to simulate core temperature distributions [16], [17]. [redacted]}(i)-(xi)} The ANSYS packages are one tool to analyze core temperature behavior.

ANSYS offers a comprehensive software suite spanning a broad range of engineering simulation. ANSYS has been used to evaluate steady-state and transient temperature evolution in the Oklo core.

For code validation, ANSYS offers the ANSYS Verification Manual, a collection of analysis problems for the user to test how ANSYS features and functions operate on a particular system. ANSYS also provides a formal commitment to the requirements of NQA-1, Subpart 2.7, Quality Assurance Requirements for Computer Software [15].

Flownex is a code used to model thermal-fluid system performance for both steady state and transient analysis. Flownex is developed under both ISO 9001:2008 and NQA-1 certified quality assurance. {

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

Table 2-7. [redacted]

[redacted]

[redacted] 1

[redacted]

Table 2-8. [redacted]

[redacted]

[redacted]

[redacted]}{(i)-(xi)}{eci}

2.1.3 Reflector System

2.1.3.1 Description of the Reflector System

The reactor core is surrounded by a reflector system. [redacted]

[redacted]

6 [redacted]

[redacted]

[redacted]

Figure 2-11. [redacted]

}{(i)-(xi)}{eci} As the reflector serves to enhance core reactivity and maintain core geometry in the most reactive configuration, failure of the reflector system would only result in a less reactive configuration.

2.1.3.2 Design Bases of the Reflector System

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Performance design bases during normal operation include the following:

- The reflector system is designed to improve fuel utilization{,
- [redacted]
- [redacted] {(i)-(xi)}{eci}.

2.1.3.3 Materials of the Reflector System

[redacted]

[redacted]

[redacted]}
{(i)-(xi)}{eci}

The maximum operating temperatures are expected to be much lower than the melting point for the reflector system materials, staying well below their thermal design limits.

2.1.3.4 Performance and Evaluation of the Reflector System

The reflector system is completely passive. [redacted]}{(i)-(xi)}{eci}

During operation, the reflector system is a passive system that enhances fuel utilization. The performance of the reflector system is analyzed using the neutron transport codes Serpent and MCNP. These codes and their models are further described in Section 2.1.2. {

2.1.4 [redacted]

2.1.4.1 [redacted]

[redacted]

[redacted]

[redacted]

Figure 2-12. [redacted]

[redacted]

[redacted]

Figure 2-13. [redacted]

[redacted]

Table 2-9. [redacted]

[redacted]

2.1.4.2 [redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

2.1.4.3 [redacted]

[redacted]

2.1.4.4 [redacted]

[redacted]

2.1.4.4.1 [redacted]

[redacted]

[redacted]

[redacted]

Figure 2-14. [redacted]

2.1.4.4.2 [redacted]

[redacted]

[redacted]

[redacted]

Figure 2-15. [redacted]

2.1.4.4.3 [redacted]

[redacted]}{(i)-(xi)}{eci}

2.2 Heat Transport System

2.2.1 Description of the Heat Transport System

The heat transport system is responsible for transporting heat from the reactor core to the heat exchanger system. The heat transport system is composed of heat pipes [redacted]}{(i)-(xi)}{eci}. The only function of the heat transport system is to transport heat from the fuel to the heat exchanger system during normal operation. The heat transport system is not required for core cooling during accident scenarios and is not credited as a barrier in Section 4.

[redacted]}{(i)-(xi)}{eci} The working fluid within each heat pipe is at subatmospheric pressure [redacted]}{(i)-(xi)}{eci}. The heat pipes operate passively; thus, the heat transport system does not include pumps or an external piping system. Because the heat pipes do not communicate hydraulically, this multiplicity provides redundant and reliable cooling and increases defense-in-depth.

Heat pipes are nearly isothermal [redacted] {(i)-(xi)}; as a result, they are often referred to as thermal superconductors. Heat pipes can operate at a wide range of temperatures, and the operational temperature range will depend upon heat pipe characteristics, including size, materials, and other characteristics. The maximum power throughput of a heat pipe is dependent on its operating temperature. When operated within specific operational temperature range, heat pipe performance increases with temperature, automatically maintaining proper power-flow ratios in the event of transients, including failure of neighboring heat pipes.

[redacted]

Table 2-10. [redacted]

[redacted]

[redacted]

Figure 2-16. [redacted]

}{(i)-(xi)}{eci}

2.2.2 Heat Transport Design Bases

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Performance design bases during normal operation include the following:

- The heat transport system passively transports heat generated in the fuel to the heat exchanger for the power conversion system during power operation,
- The heat transport system is composed of materials that are chemically compatible with one another and maintain acceptable performance under irradiation,
- The heat transport system complies with Oklo's quality assurance plan to reduce potential leaks and ruptures,
- The heat transport system is monitored continuously during operation to detect failures, and
- The heat transport system accommodates operating temperatures while maintaining appropriate mechanical limits during normal and abnormal loadings.

2.2.3 Materials of the Heat Transport System

2.2.3.1 Material Specification

The materials for the heat transport system were chosen to meet design objectives. [redacted]

Table 2-11. [redacted]

[redacted]

}{(i)-(xi)}{eci}

2.2.3.1.1 Behavior in Radiation

The materials used in the heat pipes are common materials in fast reactors with well understood behavior during irradiation. The capture cross-sections in the fast spectrum are very low; thus, the amount of activation is minimal.

2.2.3.1.2 Impurity Induced Corrosion

Impurity induced corrosion was identified as the only significant life-limiting factor heat pipe operation. [redacted]}(i)-(xi)} Proper material selection and fabrication processes can avoid this problem entirely through cleaning and high-temperature bakeoff [18].

2.2.4 Performance and Evaluation of the Heat Transport System

2.2.4.1 Heat Transport

During normal operation, each heat pipe transports heat generated in the surrounding fuel to the heat exchanger. [redacted]}(i)-(xi)}(eci) The normal operation temperature is not challenging to the heat pipes, as heat pipes safely operate at much higher temperatures.

As discussed in Section 5, the heat transport system is not required to maintain reactor cooling during abnormal events.

2.2.4.2 Subatmospheric Pressurization

The heat pipes operate at subatmospheric pressure, which is enforced during fabrication. This low pressure is beneficial because it ensures that in the very unlikely case of a heat pipe breach there is no pressure or possibility for outward explosion which would affect surrounding SSCs. {

2.2.4.3 [redacted]

[redacted]

2.2.4.4 [redacted]

[redacted]

2.2.4.5 [redacted]

[redacted]

2.2.4.6 [redacted]

[redacted]}{(i)-(xi)}{ec}

2.3 Heat Exchanger System

2.3.1 Description of the Heat Exchanger System

The heat exchanger system is designed to transfer heat from the heat transport system to the power conversion system, to convert it to electricity. After heat is generated in the reactor core, it is conducted to the heat transport system, which transports heat from the reactor core to the heat exchanger system. The heat exchanger system consists of heat exchanger units and associated piping.

[redacted]

[redacted]

Figure 2-17. [redacted]

[redacted]

[redacted]

[redacted]

Figure 2-18. [redacted]

[redacted]

[redacted]

Figure 2-19. [redacted]

[redacted]

[redacted]

Figure 2-20. [redacted]

[redacted]

[redacted]

Figure 2-21. [redacted]

}{(i)-(xi)}{eci}

2.3.2 Design Bases of the Heat Exchanger System

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Performance design bases during normal operation include the following:

- The heat exchanger system directs coolant to transfer heat from the heat transport system to the power conversion system during normal operation,
- The heat exchanger system is composed of materials that are chemically compatible with one another and with the power conversion system coolant, and maintain acceptable performance under irradiation,
- The heat exchanger system is capable of being monitored continuously during operation to detect failure,
- The heat exchanger system complies with Oklo's quality assurance plan to reduce potential leaks and ruptures,
- The heat exchanger system is designed with considerations of operating temperatures, pressures, flow rates, material degradation characteristics, creep, fatigue, stress rupture, and other conditions under operating, maintenance, testing, and postulated accident conditions, with relevant uncertainties, and
- The heat exchanger system provides balanced pressures to the power conversion system.

2.3.3 Materials of the Heat Exchanger System

The heat exchanger system is constructed primarily of stainless steel. Stainless steel was chosen because of its suitability at the operating temperature, pressure and heat flux[redacted]{(iii), (iv), (ix)-(xi)}.

2.3.4 Performance and Evaluation of the Heat Exchanger System

The primary function of the heat exchanger system during normal operation is to assure that each heat pipe is able to transfer the proper amount of heat to the power conversion system coolant. [redacted]

[redacted]

[redacted]

Table 2-12. [redacted]

[redacted]

[redacted]}{(i)-(xi)}{eci}

2.4 Engineered Performance Systems

2.4.1 Summary Description

The engineered performance systems are designed for flexibility in the operating margin of the Oklo design. [redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]}{(i)-(xi)}{eci}

2.4.2 Reactor Enclosure System

2.4.2.1 Description of the Reactor Enclosure System

[redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted] {(i)-(xi)}{eci} All reactor enclosures are constructed from stainless steel{[redacted]}{(i)-(xi)}. The atmospheres of all reactor enclosure are backfilled with an inert gas. [redacted]

[redacted]

Figure 2-22. [redacted]

}{(i)-(xi)}{eci}

The reactor enclosures do not serve as a pressure boundary because all portions of the core are at or slightly below atmospheric pressure throughout the entire fuel cycle life. Additionally, the reactor enclosures are not leak tight and are not assumed as such in Section 4 and Section 5. {

2.4.2.2 [redacted]

2.4.2.2.1 [redacted]

[redacted]

[redacted]

2.4.2.2.2 [redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]

2.4.2.2.3 [redacted]

[redacted]

2.4.2.2.4 [redacted]

[redacted]

2.4.2.3 [redacted]

2.4.2.3.1 [redacted]

[redacted]

2.4.2.3.2 [redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]

2.4.2.3.3 [redacted]

[redacted]

2.4.2.3.4 [redacted]

[redacted]

2.4.2.4 [redacted]

2.4.2.4.1 [redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

2.4.2.4.2 [redacted]

[redacted]

- [redacted]
- [redacted]

2.4.2.4.3 [redacted]

[redacted]

2.4.2.4.4 [redacted]

[redacted]

2.4.3 [redacted]

2.4.3.1 [redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]

Table 2-13. [redacted]

[redacted]

[redacted]

Figure 2-23. [redacted]

[redacted]

[redacted]

[redacted]

Figure 2-24. [redacted]

[redacted]

[redacted]

2.4.3.2 [redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

2.4.3.3 [redacted]

[redacted]

[redacted]

2.4.3.4 [redacted]

[redacted] {(i)-(xi)}{eci}

2.4.4 Air Cooling System

2.4.4.1 Description of the Air Cooling System

The air cooling system is a completely passive system that utilizes natural convection to remove decay-heat levels of heat during all modes of operation. [redacted] {(i)-(xi)}{eci} Air flow through the air cooling system is driven by the differential hydrostatic force between cool outside air from the inlet to the module and heated air from the module to the air outlets.

The air cooling system operates continuously in all plant operating modes. The design has no valve or active component. [redacted]

[redacted]}{(i)-(xi)}{eci}

2.4.4.2 Air Cooling System Design Bases

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Performance design bases during normal operation include the following:

- The air cooling system functions to remove decay-heat levels of heat during all modes of operation,
- The air cooling system functions to maintain reactor enclosure temperatures within their limits,
- The air cooling system functions to remove all decay heat indefinitely following a reactor trip,
- The air cooling system is designed such that the air does not become significantly activated,
- The air cooling system functions completely passively without active equipment such as fans and power sources, and
- The air cooling system is designed with sufficient redundancy to perform its functions.

2.4.4.3 Materials of the Air Cooling System

The air cooling system is constructed of materials selected for acceptable structural integrity and corrosion resistance. [redacted]}{(i)-(xi)}{eci}

2.4.4.4 Performance and Evaluation of the Air Cooling System

2.4.4.4.1 Modes of Operation

The air cooling system operates continuously in all plant operating modes. The air cooling system is a passive system with no valves or active component. [redacted] {(i)-(xi)}{eci}

2.4.4.4.2 Instrumentation and Control

The air cooling system is a passive system and, therefore, has no controls. [redacted]}{(iii), (iv), (ix)-(xi)}

2.5 Instrumentation and Control System

2.5.1 Summary Description

The instrumentation and control system contains the components and systems required to monitor and control performance of the Oklo plant. These systems are used for operational control of the plant and include the following:

- Reactor trip system (Section 2.5.2),
- Reactivity management system (Section 2.5.3),
- Plant control system (Section 2.5.4),
- Post-accident monitoring system (Section 2.5.5), and
- Information display system (Section 2.5.6).

2.5.2 Reactor Trip System

2.5.2.1 Description of the Reactor Trip System

The reactor trip system initiates actions necessary for reactor shutdown. The reactor trip system also provides signals to other systems, including the reactivity management system and information display system. [redacted]

- [redacted]
- [redacted]}{(i)-(xi)}{eci}

The reactor trip system is composed of the sensors, initiating circuits, logic, bypasses, and actuated devices that ensure the reactor trips when monitored system parameters exceed preestablished limits. The reactor trip system has three divisions, each independent and redundant from one another. Each division is capable of initiating and maintaining a reactor trip regardless of the condition of the other two divisions. The reactor trip employs a redundant and diverse design to ensure with a high degree of confidence that a reactor trip is initiated and completed when setpoints are exceeded while reducing the likelihood of an inadvertent reactor trip. [redacted] {(i)-(xi)}{eci}

2.5.2.1.1 Neutron Flux Instrumentation

[redacted]}{(i)-(xi)}{eci} Neutron flux detectors determine core parameters such as overpower and provide continuous measurement of the core's global power distribution. Flux monitors provide the most rapid indication of any potential overpower condition and are used to protect the integrity of the fuel for investment protection reasons by initiating a reactor trip.

[redacted]

[redacted]

[redacted]

Figure 2-25. [redacted]

[redacted]

Figure 2-26. [redacted]

}{(i)-(xi)}{eci}

2.5.2.1.2 Heat Pipe Temperature Instrumentation

The temperature limits in the Oklo design are based on fuel temperature. Because heat pipes are nearly isothermal, fuel temperatures can be inferred from heat pipe temperatures. [redacted]}{(i)-(xi)}{eci}

2.5.2.2 Design Bases of the Reactor Trip System

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Performance design bases during normal operation include the following:

- The reactor trip system automatically initiates a reactor trip when preestablished setpoints are exceeded during any condition of normal operation, including anticipated operational occurrences,
- [redacted]{(i)-(xi)}{eci}

- The reactor trip system allows periodic in-service testing when the reactor is in operation,
- The reactor trip system seals in a reactor trip once initiated and requires deliberate action to return to normal operation, and
- The reactor trip system is designed to fail in the tripped condition.

2.5.2.3 Materials of the Reactor Trip System

The materials in the reactor trip system are chosen to withstand normal and abnormal conditions.

2.5.2.4 Performance and Evaluation of the Reactor Trip System

2.5.2.4.1 Trip Signals

Initiating signals to trip the reactor include the following:

- Overpower{[redacted]}{(i)-(xi)}{eci},
- Underpower{[redacted]}{(i)-(xi)}{eci},
- Overtemperature{[redacted]}{(i)-(xi)}{eci},
- Undertemperature{[redacted]}{(i)-(xi)}{eci}, and
- Ground acceleration that exceeds the operating basis earthquake.

It is important to note that the trip signals described here are for normal operations. {[redacted]}{(i)-(xi)}{eci}

To ensure that a trip signal goes to completion, it is only necessary that the process sensors (e.g., flux, temperature) remain in a tripped condition for a sufficient length of time to the seal-in circuitry. Once this action is accomplished, the trip logic proceeds to initiate reactor trip regardless of the state of the sensors that initiated the sequence of events.

2.5.2.4.2 Operating Conditions

The operating conditions for sensors in the reactor trip system are such as to withstand the environment during normal operations. {

2.5.2.4.3 [redacted]

[redacted]

[redacted]

[redacted]

[redacted]}{(i)-(xi)}{eci}

2.5.2.4.4 Testing

Prior to operation, the reactor trip system undergoes pre-service inspection, calibration, and testing. During operation, the reactor trip system undergoes periodic in-service testing to ensure its performance remains acceptable for asset protection reasons.

2.5.3 Reactivity Management System

2.5.3.1 Description of the Reactivity Management System

The reactivity management system monitors performance parameters in the reactor and can adjust core reactivity. [redacted]

[redacted]

2.5.3.1.1 [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.5.3.1.2 [redacted]

[redacted]

2.5.3.1.3 [redacted]

[redacted]

2.5.3.1.4 [redacted]

[redacted]}{(i)-(xi)}{eci}

2.5.3.2 Design Bases of the Reactivity Management System

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Performance design bases during normal operation include the following:

- The reactivity management system automatically maintains core criticality during power operation,
- [redacted]}{(i)-(xi)}{eci} and
- The reactivity management system monitors reactor core performance.

2.5.3.3 Materials of the Reactivity Management System

The materials used in the reactivity management system are chosen to maintain acceptable performance in expected normal and abnormal operating conditions. {

2.5.3.4 [redacted]

2.5.3.4.1 [redacted]

[redacted]

2.5.3.4.2 [redacted]

[redacted]

2.5.3.4.3 [redacted]

[redacted] {(i)-(xi)}{eci}

2.5.4 Plant Control System

2.5.4.1 Description of the Plant Control System

The plant control system monitors plant-wide process parameters and can control components in the power conversion system to ensure optimal operation of the Oklo plant. {

2.5.4.1.1 [redacted]

[redacted]

2.5.4.1.2 [redacted]

[redacted]

2.5.4.1.3 [redacted]

[redacted]

2.5.4.1.4 [redacted]

[redacted]

2.5.4.1.5 [redacted]

[redacted]

[redacted]}{(i)-(xi)}{eci}

2.5.4.2 Design Bases of the Plant Control System

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Performance design bases during normal operation include the following:

- The plant control system monitors and controls performance of the power conversion system,
- The plant control system allows initiation and termination of turbine bypass mode,
- The plant control system monitors plant performance parameters, and
- The plant control system allows a manual turbine trip.

2.5.4.3 Materials of the Plant Control System

Materials in the plant control system are chosen to maintain acceptable performance in normal and off-normal operating conditions. [redacted]}{(iii), (iv), (ix)-(xi)}

2.5.4.4 Performance and Evaluation of the Plant Control System

2.5.4.4.1 Alarm Signals

The following conditions are examples of abnormal conditions that indicate that the plant has exceeded or will exceed limits:

- Turbine trip,
- Overspeed of turbine,
- Underspeed of turbine,
- Leak in the power conversion system,
- [redacted]}{(i)-(xi)}{eci}

2.5.4.4.2 Turbine Bypass

Initiation and termination of turbine bypass mode is controlled by the plant control system. Turbine bypass mode directs the power conversion system coolant through a bypass loop instead of the turbine-generator set during minor outages of the turbine. Specifically, the valves used to direct flow through the power conversion system are controlled by the plant control system.

2.5.4.4.3 Display

Measurements from the plant control system are sent to the information display system using one-way, read-only signals for display and recording.

2.5.4.4.4 Testing

Prior to operation, the plant control system undergoes pre-service inspection, calibration, and testing. During operation, the plant control system undergoes periodic in-service testing to ensure its performance remains acceptable.

2.5.5 Post-Accident Monitoring System

2.5.5.1 Description of the Post-Accident Monitoring System

The post-accident monitoring system measures plant-wide process parameters after an accident to ensure the reactor is shutdown. [redacted]

- [redacted]
- [redacted]

[redacted]

2.5.5.1.1 [redacted]

[redacted]

2.5.5.1.2 [redacted]

[redacted]

2.5.5.1.3 [redacted]

[redacted]

2.5.5.1.4 [redacted]

[redacted]

2.5.5.1.5 [redacted]

[redacted]

2.5.5.1.6 [redacted]

[redacted]

2.5.5.1.7 [redacted]

[redacted]}{(i)-(xi)}{eci}

2.5.5.2 Design Bases of the Post-Accident Monitoring System

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Performance design bases during normal operation include the following:

- The post-accident monitoring system ensures the reactor core remains shut down and within fuel temperature limits{,
- [redacted]
- [redacted]}{(i)-(xi)}.

2.5.5.3 Materials of the Post-Accident Monitoring System

Materials in the post-accident monitoring system are chosen to maintain acceptable performance in normal and off-normal operating conditions.

2.5.5.4 Performance and Evaluation of the Post-Accident Monitoring System

2.5.5.4.1 Power Source

Following an accident, the post-accident monitoring system continues to monitor the status of the plant. [redacted]

2.5.5.4.2 [redacted]

[redacted]

2.5.5.4.3 [redacted]

[redacted]

2.5.6 [redacted]

2.5.6.1 [redacted]

[redacted]

2.5.6.2 [redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]

2.5.6.3 [redacted]

[redacted]

2.5.6.4 [redacted]

2.5.6.4.1 [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.5.6.5 [redacted]

[redacted]

1. [redacted]

[redacted]

2.5.6.5.1 [redacted]

[redacted]}{(i)-(xi)}{eci}.

2.6 Electric System

2.6.1 Summary Description

The electric power systems supply continuous power to equipment required for startup, normal operation, and shutdown of the reactor under normal operating conditions. This section is focused on the description of power distribution during normal operations. [redacted] {(i)-(xi)} The Oklo design is intended to serve communities in off-grid locations and is completely grid independent. A connection to an offsite transmission grid is used only to distribute the power generated by the Oklo reactor to electricity consumers. Thus, the transmission grid is more representatively described as an electrical load rather than a source of electrical power. [redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]

Figure 2-27. [redacted]

}{(i)-(xi)} Systems that are used to shut down the reactor are passive and do not require electricity. This is a key characteristic to Oklo's inherent safety because these systems can be maintained indefinitely in a safe shutdown through natural forces and simplicity of design. Therefore, the design is independent of onsite and offsite power for safe operation.

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)} No specific description of materials or performance and evaluation are provided for this pilot effort. {

2.6.2 [redacted]

2.6.2.1 [redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]

2.6.2.2 [redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

2.6.3 [redacted]

2.6.3.1 [redacted]

[redacted]

[redacted]

Figure 2-28. [redacted]

2.6.3.2 [redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]

2.6.4 [redacted]

2.6.4.1 [redacted]

[redacted]

2.6.4.2 [redacted]

[redacted]

[redacted]

- [redacted]}{(i)-(xi)}

2.7 Auxiliary Systems

2.7.1 Summary Description

The auxiliary systems for the Oklo plant are those that are typically not associated with the production of heat for electric generation. [redacted]

- [redacted]
- [redacted]
- [redacted]

2.7.2 [redacted]

2.7.2.1 [redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

2.7.2.2 [redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]

2.7.3 [redacted]

2.7.3.1 [redacted]

[redacted]

[redacted]

2.7.3.2 [redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]

2.7.3.3 [redacted]

[redacted]

2.7.3.4 [redacted]

[redacted]

[redacted]

2.7.4 [redacted]

2.7.4.1 [redacted]

[redacted]

2.7.4.2 [redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]

2.7.4.3 [redacted]

[redacted]

2.7.4.4 [redacted]

[redacted]

[redacted]

{(i)-(xi)}{eci}

2.7.5 Other Auxiliary Systems

Because these are auxiliary support system, they are only briefly described in this section. No specific design bases, description of materials, or performance and evaluation are provided. Additionally, this section shows a partial list of auxiliary systems, which is as follows:

- Potable and sanitary water system (Section 2.7.5.1),
- Air conditioning, heating, cooling, and ventilation system (Section 2.7.5.2),
- Communication system (Section 2.7.5.3), and
- Lighting system (Section 2.7.5.4).

2.7.5.1 Potable and Sanitary Water System

The potable and sanitary water system provides water for general purposes throughout the plant. The water is used for human consumption, sanitary and domestic purposes. Water for the potable and sanitary water system will be site-specific and pretreated at the source to meet applicable water quality standards.

2.7.5.2 Air Conditioning, Heating, Cooling, and Ventilation System

The air conditioning, heating, cooling, and ventilation system serves the site building and is designed to maintain a controlled environment for the comfort of personnel.

2.7.5.3 Communication System

The communication system provides reliable and effective communications inside the site building (intra-plant) and with external locations (plant-to-offsite) during normal operation, maintenance, transient, fire, and emergency conditions including loss of offsite power and security-related events.

2.7.5.4 Lighting System

The plant lighting system provides adequate lighting during all plant operating conditions (e.g., normal operation, fire, and emergency conditions). The physical security system relies on normal plant lighting and emergency plant lighting to support the successful implementation of security functions.

2.8 Power Conversion System

2.8.1 Description of the Power Conversion System

The power conversion system functions to convert heat energy to electricity and to operate in turbine bypass mode (see Section 2.5.4). [redacted] {(iii), (iv), (ix)-(xi)}

2.8.2 Power Conversion System Design Bases

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Performance design bases during normal operation include the following:

- The power conversion system utilizes heat from the heat transport system to create electricity during power operation,
- The power conversion system provides the capability for complete bypass flow in the event of a turbine trip,
- The power conversion system provides the capability for storing the full volume of coolant during reactor maintenance, and
- The power conversion system turbine trips automatically under abnormal conditions.

2.8.3 Materials of the Power Conversion System

The design, manufacture, shipping, and other attributes of the power conversion system will comply with Oklo quality assurance. Further information for this section will be provided at a later date.

2.8.4 Performance and Evaluation of the Power Conversion System

The performance and evaluation of the power conversion system will comply with Oklo quality assurance. Further information for this section will be provided at a later date.

3 RADIOACTIVE MATERIALS TO BE PRODUCED IN OPERATION

3.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(3) requires the following:

> The kinds and quantities of radioactive materials expected to be produced in the operation and the means for controlling and limiting radioactive effluents and radiation exposures within the limits set forth in part 20 of this chapter

The purpose of this section is to provide an overview of the radioactive materials that are produced during normal operation of the Oklo reactor and how they are controlled.

3.0.1 Modes of Operation Considered

For purposes of this initial analysis, radioactive materials at normal operations are considered.

3.0.2 Source of Activation Considerations

Sources of activation aside from the fluence of the core are assumed to be negligible and are not accounted for in this analysis. For the purpose of this preliminary analysis for the production of radioactive materials during operation, the fluence from the core is used as the bounding factor. The following are the considerations for this analysis:

- Spent fuel within the reactor core is the sole source of activation, and
- Radioactive materials considered are those produced resulting from normal operations.

The Oklo reactor is deliberately designed to limit the total amount of radioactive materials produced during operation. Any additional materials identified from additions to the design that are exposed to the core radiation field will be added and analyzed.

3.1 Introduction

Radioactive materials that are produced during normal operation of the Oklo reactor include materials that may receive any exposure from the core radiation field. Although activation levels vary depending on distance from the core, time irradiated, and shielding, all materials within that core radiation field are discussed to provide a comprehensive understanding of the management of those materials. Where possible, materials are deliberately chosen to help mitigate the secondary radiation effects, reducing exposure and dose rates. [redacted] }{(i)-(xi)}{eci}

3.2 Controlling Sources of Radiation

Radioactive materials that are produced during normal operation of the Oklo reactor include radioactive fluids and structural materials.

3.2.1 Fluids

Potential radioactive fluids, or effluents, inside the reactor module include fission products, backfill gas, power conversion system coolant, and the air circulating through the air cooling system. The total fission product inventory generated by end of fuel cycle life is expected to be small and completely retained inside the fuel matrix. The backfill gas is inert and expected to remain fully inside the reactor module. The power conversion system coolant is not expected to reach substantial activation levels and is expected to remain completely within the enclosed power conversion system. Lastly, the air circulating within the air cooling system has a low residency time and is also not expected to activate.

3.2.1.1 Fission Products

The Oklo fuel {[redacted]}{(i)-(xi)}{eci} generates little fission products. {[redacted]}{(i)-(xi)}{eci} Additionally, the Oklo reactor is not expected to operate with any damaged reactor cells, which inhibits fission product release to the reactor module during normal operations keeping both the capsule and the module shell radiologically clean. Further, Section 5, describes deterministic safety analyses that evaluate consequences related to potential fission product releases.

3.2.1.2 Reactor Enclosure Backfill Gas

The reactor enclosures are backfilled with inert gas, which is expected to remain within the reactor enclosures through fuel cycle life. The Serpent Monte Carlo code, described in Section 2.1.2, is used to determine activated amounts of inert gas. {[redacted]

Table 3-1. [redacted]

[redacted]

} {(i)-(xi)}{eci}

3.2.1.3 Power Conversion System Coolant

The power conversion system coolant uses fluid {[redacted]}{(i)-(xi)} to transport heat from the heat exchanger system to the power conversion system. The fluid is appropriately shielded

by the axial shielding system and is removed from direct exposure of the core radiation field. Because of the location and protected environment of the power conversion system, the fluid activation levels are expected to be minimal. Additional analysis will be conducted to confirm this expectation.

3.2.1.4 Air Cooling System Coolant

The air circulating through the air cooling system is air pulled in from the surrounding environment. During normal operations, clean air passes through the air cooling system at a flow velocity of 7.30 m/s. This high flow velocity minimizes residency time of the air in the air cooling system leading to minimal irradiation if the air. The air cooling system is located outside of the reactor enclosures, well protected from the core radiation field by the radial modular shielding. Due to the protection of the air cooling system and the small residency time of the air circulating through the air cooling system, it is expected that activation levels are negligible.

3.2.2 Structural and Other Materials

Non-fluid materials include structural and other materials inside the reactor module that become activated during operations. [redacted] }{(i)-(xi)}{eci} All core components are shielded, stationary, and sealed during normal operations, precluding access to core components. Therefore, structural materials and other materials are easily shielded and mitigated to protect onsite personnel and the public from any additional exposure that would originate from these materials.

Radiological significance of these materials during maintenance or decommissioning is outside the scope of this pilot submittal and will be provided at a later date.

4 PROBABILISTIC RISK ASSESSMENT

4.0 Purpose and Scope

Probabilistic risk assessment (PRA) is required by *Title 10 to the Code of Federal Regulations* Section 52.79(a)(46) and is applied to the Oklo design during the design process. Specifically, it is applied to confirm that risk to the public is acceptably low for licensing basis events.

The goal of this PRA is to evaluate the following items:

- The overall additional risk to the public from the Oklo design,
- The major contributors to that additional risk, and
- The impact of varying specified parameters to the overall risk.

4.0.1 Events Modeled

The following types of events have been modeled or accounted for in this preliminary PRA:

- Accidents that are confined to a plant,
- Accidents that are assumed to occur at full power, and
- Accidents that involve only the spent fuel[7] within the reactor core as a source of radioactivity.

The following have not been modeled or accounted for in this preliminary PRA but will likely be part of future work:

- Risks from external events[8],
- Risks from acts of sabotage or normal plant releases,
- Risks from human actions, and
- Accidents at other operating conditions outside of full power.

[7] Fuel is conservatively assumed to be 50% beyond the fuel cycle life for these analyses.

[8] Seismic events have traditionally been considered the most limiting external events for metallic fueled fast reactors, primarily due to the possibility of large induced positive reactivity insertions caused by control rod motion relative to the core lattice [19]. [redacted] {(i)-(xi)}{eci}

4.0.2 Consideration of Uncertainties

The level of detail of the PRA is consistent with this pilot submittal. The values selected for failure probabilities are considered to be broadly representative and thus acceptable at this stage in the design process but may need to be supplemented as the design progresses.

4.1 Introduction to Dynamic Probabilistic Risk Assessment

4.1.1 Relationship to Traditional Safety Analysis

A traditional approach to safety analysis generally involves deterministic accident simulations and results evaluations, which are then used to create probabilistic event sequences (i.e., event trees) as part of assessing the potential risk of abnormal events. Simulation tools and general engineering understanding of the various plant systems are used to inform multiple potential progressions of abnormal events and the risk that their consequences pose to health and safety of the public. Thus, in the traditional approach, the deterministic safety analysis tools are used to implicitly inform the creation and analysis of probabilistic outcome estimations, such as event trees, which are used in PRA.

Dynamic PRA (DPRA) is a more holistic use of PRA in which traditional PRA methods are integrated directly with simulation tools, an approach enabled by modern computational methods and computing power [20]. This integration enables the generation of a dynamic event tree, which branches based on conditions achieved from simulations in real time. In the DPRA approach, safety analysis tools are explicitly used to provide simulations of probabilistic outcomes. With DPRA, the dynamic event tree is also the actual safety code simulation. A distinction no longer exists between performing safety analyses and constructing probabilistic branching event sequences: both are done simultaneously, in a single analysis step.

A powerful capability of DPRA is that the safety response space can be more fully explored, while also tracking the likelihood of each sequence. Properly employed, this enables a greater understanding of the system behavior while also providing for increased focus on event pathways with highest safety significance.

Ultimately, DPRA enables multiple risk and safety analyses to be evaluated simultaneously. Because a range of inputs and outcomes can rapidly be modeled, effects of uncertainties can quickly be assessed and analyzed directly [21]. This method can illuminate events which may not have been thought of otherwise. Integrating PRA with safety analyses may make PRA even more relevant and important for assessing first-of-a-kind reactors than old existing reactors, despite that the opposite has been conjectured.[9]

In SECY-07-0192, "Agency Long-Term Research Activities for Fiscal Year 2009," the NRC recognized the potential for advanced PRA methodology. Among other benefits, advanced PRA would:

- Reduce reliance on unnecessary modeling simplifications (i.e. more phenomenological),
- Make process and results more scrutable,

[9] Advisory Committee for Reactor Safeguards Transcript, ML18149A563, April 2018.

- Leverage advances in computational capabilities and technology developments, and
- Allow for ready production of uncertainty characterization.

The most promising approach to improving PRA through these advancements was identified as the dynamic event tree approach [22]. This is the DPRA approach taken by Oklo.

4.1.2 Branching Conditions

A DPRA analysis resembles a sensitivity study, where multiple simulations are run concurrently so that the phase space of the system behavior is more fully understood. The difference between the two lies primarily in how the range of simulations are actually conducted: in a sensitivity study, one or more problem parameters are selected a priori and then varied over a predefined range, performing a new, full simulation for each value or set of values. Conversely, in a DPRA analysis, the user defines branching conditions, which are problem parameters or characteristics at which point the simulation is split into multiple additional simulations in real time, each with new parameter values or system states, to explore multiple potential outcomes of that branching event as the event evolves.

These branching conditions reflect real-world states where system behavior may diverge. Each branching condition is prescribed by the following parameters:

- The reactor state at which it is triggered, and
- The multiple resulting branch states that follow, together with the specified probability of that branch's occurrence.

For example, a typical branching condition definition for a reactor safety DPRA is the set of reactor trip setpoint values, such as a temperature or flux. The user specifies this set of reactor state values as part of a "reactor trip" branching condition, and if the simulation tool reaches any of these set points, the simulation stops and several new simulation branches are spawned, each capturing potential outcomes that may occur after reaching those conditions.

The user defines each of these potential outcomes in terms of how the plant state might differ at that stopping criterion and provides the probability of occurrence for each branch. In the reactor trip example, upon reaching a reactor trip setpoint, two branches may be defined: one with a successful reactor scram (probability of 0.9999997/demand), and one with a reactor scram failure (probability of 3×10^{-7}/demand). The simulation tool will then be run for each of these potential conditions, and an event tree tracking the multiple branching outcomes is generated dynamically, which when combined with the user-defined branching probabilities and initiating event frequency, forms the basis for the DPRA.

In addition to defining the problem conditions at which multiple potential outcomes may result, the initiating event frequencies (i.e. failure probabilities) are defined. When the DPRA generates the dynamic event tree, it uses the individual event frequencies to calculate the expected frequency of occurrence for each full sequence that is calculated upon termination. These sequence probabilities are then displayed in the blocks of the dynamic event tree graph where the sequence terminates. By convention, the full sequence of events that leads to a particular end state is assigned the same numerical identifier as that end state.

4.2 Methodology

The first step before performing the risk analysis is to establish a complete set of events. This selection is aided by a systematic review of the following resources:

- Search over operating lifecycle for the normal mode of operation for the Oklo design,
- Review of generic events to all nuclear reactors,
- Review of metallic-fueled fast reactor operating experience,
- Review of compact reactor operating experience and analytical methods,
- Review of light water reactor events, and
- Review of expert opinion on similar conceptual designs.

4.2.1 Reactor Trip Setpoint Branching Conditions

The Oklo reactor is a very small and simple system, so defining branching conditions is straightforward. Reactor trip setpoints were kept constant for both the transient overpower and decrease of heat removal events{[redacted]

Table 4-1. [redacted]

[redacted]

}{(i)-(xi)}{eci} Next, specific branching conditions are applied for the increase of heat generation (i.e., transient overpower) and the decrease of heat removal events.

4.2.2 Transient Overpower

{

4.2.2.1 [redacted]

[redacted]

[redacted] }(i)-(xi)}(eci}

4.2.2.2 Derivation of Branching Conditions Probabilities

The transient overpower initiating event frequencies and reactor trip failure probabilities are estimated based on a review of historical data sources, primarily focused on the PRISM preliminary safety information document (PSID) and referencing historic light water reactor operating data, where appropriate [19], [23], [24]. {

4.2.2.3 [redacted]

[redacted]

Table 4-2. [redacted]

[redacted]

}{(i)-(xi)}{eci}

4.2.2.4 Reactor Trip Setpoint Branching Conditions

Once a reactor trip setpoint has been reached during a transient overpower event, two outcomes are possible. The first is a successful reactor trip[redacted]

- [redacted]
- [redacted]}{(i)-(xi)}{eci}.

The second is a failed reactor trip[redacted]

- [redacted]
- [redacted]}{(i)-(xi)}{eci}.

Note that for the transient overpower event analysis, failure of the power conversion system heat removal during turbine bypass mode was initially modeled, but ultimately excluded from the final reported results. These failed turbine bypass sequences are excluded because the resulting event sequence occurrence frequencies are exceptionally small (less than 10^{-12}/reactor-year). [redacted]

Table 4-3. [redacted]

[redacted]

}{(i)-(xi)}{eci}

4.2.3 Decrease of Heat Removal

4.2.3.1 Overview of Event

The power conversion system is the only significant credited means that is capable of fully removing the heat generated by the reactor at full power that is modeled for this analysis. Thus, bounding initiating events that involve a reduction of heat removal from the core while at power entirely consist of those where the operation of the power conversion system is disrupted.

The most frequent power conversion system disruption is a turbine trip, with an estimated frequency of occurrence of 1/reactor-year[10]. Upon a turbine trip, the power conversion system is designed to open the turbine bypass valves and reject up to 100% of the full operating load. However, in this analysis, the turbine bypass heat removal mode is conservatively assumed to remove only 95% of nominal power.

4.2.3.2 Derivation of Branching Conditions Probabilities

As with the transient overpower event, the failure probabilities for the decrease of heat removal event are estimated based on historical data that is considered to be broadly representative. Both the turbine trip frequency and the power conversion system heat rejection mode availability are based on PRISM estimates for similar systems [19].

4.2.3.3 Initiating Event Branching Conditions

The probability per demand of power conversion system turbine bypass failure is 2×10^{-3}, meaning that the turbine bypass heat rejection mode is available 99.8% of the time per demand. With a turbine trip frequency of 1/reactor-year, successfully operating the turbine bypass is estimated at a frequency of 0.998/reactor-year, and a failed turbine bypass initiating event is thus estimated to have a frequency of 2×10^{-3}/reactor year. For this analysis, the values shown in Table 4-4 are used for the initiating event branching conditions.

Table 4-4. Decrease of heat removal initiating event branching conditions

Initiating event branching condition	Cooling fraction	Estimated frequency per reactor-year
Turbine bypass heat removal functional	0.95	9.98E-01
Turbine bypass heat removal nonfunctional	0	2.00E-03

{

4.2.3.4 [redacted]

[redacted]

Table 4-5. [redacted]

[redacted]

[10] The Oklo DPRA discusses frequencies in terms of "reactor-year" because an Oklo unit (i.e., plant) is composed of a single reactor and a single power conversion system.

[redacted]

}{(i)-(xi)}{eci}

4.3 Results

Analytical tools used for this DPRA include [redacted] }{(i)-(xi)}{eci} ADAPT, developed by Sandia National Laboratory [23].

The Oklo design employs reactor trip setpoints, which initiate a reactor trip and a turbine trip. The term "protected" means that, when called upon, reactor trip is successful. Conversely, "unprotected" is used to mean that, when called upon, reactor trip is unsuccessful. {

4.3.1 [redacted]

[redacted]

11 [redacted]

[redacted]

Figure 4-1. [redacted]

4.3.1.1 [redacted]

[redacted]

12 [redacted]

13 [redacted]

[redacted]

Figure 4-2. [redacted]

[redacted]

Figure 4-3. [redacted]

4.3.1.2 [redacted]

[redacted]

[redacted]

[redacted]

[redacted]

[redacted]

4.3.1.3 [redacted]

[redacted]}{(i)-(xi)}{eci}

4.3.2 Decrease of Heat Removal

The decrease of heat removal initiating event branching condition included two outcomes:

1. Successful operation of the power conversion system in bypass mode, with 95% of full power heat removal, or

2. Failure of the power conversion system to operate in bypass mode, with 0% of full power heat removal.

[redacted]

[redacted]

[redacted]}{(i)-(xi)}{eci}

No turbine trip is included upon reaching the reactor trip setpoint because the turbine is assumed to have already tripped as part of the initiating event. [redacted]

[redacted]

Figure 4-4. [redacted]

[redacted]

[redacted]

Figure 4-5. [redacted]

[redacted]

Figure 4-6. [redacted]

}{(i)-(xi)}{eci} With the failed turbine bypass branch of the initiating event, the next branching point reached is the reactor trip setpoint. [redacted] {(i)-(xi)}{eci}

4.3.3 Summary of Results

[redacted]

Table 4-6. [redacted]

[redacted]

}{(i)-(xi)}{eci}

These DPRA results offer risk-informed insights on the progression of abnormal events for the Oklo design. Specifically, the eight sequences modeled demonstrate that even unlikely

14 [redacted].

abnormalities are not exceptionally challenging to the Oklo plant. These DPRA results are further analyzed and classified in Section 5.

5 DESIGN AND PERFORMANCE OF STRUCTURES, SYSTEMS, AND COMPONENTS

5.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(5) requires the following:

> An analysis and evaluation of the design and performance of structures, systems, and components with the objective of assessing the risk to public health and safety resulting from operation of the facility and including determination of the margins of safety during normal operations and transient conditions anticipated during the life of the facility, and the adequacy of structures, systems, and components provided for the prevention of accidents and the mitigation of the consequences of accidents. Analysis and evaluation of ECCS cooling performance and the need for high-point vents following postulated loss-of-coolant accidents shall be performed in accordance with the requirements of §§ 50.46 and 50.46a of this chapter.

It is important to note that 10 CFR 50.46, "Acceptance criteria for emergency core cooling systems for light-water nuclear power reactors," does not apply to the Oklo design because the Oklo design is not a light water reactor and does not require a corresponding system to the emergency core cooling system.

The purpose of this section is to document the methodology and approach to transient and accident analyses performed by Oklo for the licensing basis as well as the methodology for classification of structures, systems, and components (SSCs). These analyses cover a spectrum of events within the design bases, referred to as design basis events (DBEs), as well as consideration of beyond design basis events (BDBEs). The results of transient and accident analyses demonstrate an adequate plant response to challenging conditions, conformance with applicable regulations concerning SSC performance and postulated radiological consequences, and show that adequate protection of the public is expected during the plant lifecycle. The goal of this analysis is to identify any necessary safety-related functions from the DBE set, and the corresponding SSCs. The method for licensing basis event (LBE) selection for the Oklo design is risk-informed, drawing on probabilistic risk assessment (PRA) done at different stages of the design but also imposing stricter bounds where data is unavailable.

5.0.1 Modes of Operation Considered

For purposes of this initial analysis, only events at normal operations are considered.

5.0.2 Applied Guidance

Oklo informed its LBE selection process via the Licensing Modernization Project (LMP) risk-informed performance-based guidance, anticipated to be reviewed under draft regulatory guide (DG)-1353, "Guidance For A Technology-Inclusive, Risk-Informed, and Performance-Based Approach to Inform the Content of Applications for Licenses, Certifications, and Approvals for Non-Light-Water Reactors." The specific LMP guidance used throughout this document is, "Risk-Informed Performance-Based Guidance for Non-Light Water Reactor Licensing Basis

Development," Revision L, issued May 25, 2018. The LMP guidance is applied as much as is appropriate and deviations or suggestions are noted as necessary.

5.1 Selection of Licensing Basis Events

5.1.1 Overview of Methodology

Oklo recognizes that a general challenge to nonlight water reactor design analyses is limited operating experience. However, many aspects of the Oklo design are built from technologies with extensive operating experience, for instance:

- The existing data from thirty years of operation of metal fueled reactors such as the Experimental Breeder Reactor (EBR)-II,
- Mature probabilistic risk assessments of metal-fueled reactors such as the EBR-II reactor as well as the PRISM reactor, and
- Materials and components data from both reactor operation and experiments.

Regardless, Oklo intends to demonstrate a comprehensive analysis that utilizes appropriate conservatisms to address uncertainty regarding the LBE selection processes. The LMP guidance is one approach that is used within Oklo's LBE selection process that is based on conservative risk metrics.

The Oklo LBE selection process is a modified process that is based on the steps outlined in Figure 3-2 of the LMP guidance [25] and includes the following steps:

1. Creating an exhaustive list of possible events and proposing initial LBEs,
2. Performing risk analysis,
3. Categorizing events and selecting bounding LBEs,
4. Evaluating the bounding LBEs against the frequency-consequence target,
5. Evaluating the bounding LBEs against the integrated risk targets,
6. Evaluating the bounding DBAs for dose implication, and
7. Selecting safety functions.

Licensing basis event selection considered all events during normal operations. The frequencies for LBEs are informed by the LMP guidance and are shown in Table 5-1; these frequencies are largely equivalent to the ones documented in the LMP guidance.

Table 5-1. Frequencies of licensing basis events

Licensing Basis Event Category	Frequency, f (per reactor-year)
Anticipated Operational Occurrence	1E-1 > f ≥ 1E-2
Design Basis Event	1E-2 > f ≥ 1E-4

Beyond Design Basis Event	1E-4 > f ≥ 5E-7
Design Basis Accident	Not applicable [a]

[a] Since design basis accidents are analyzed under deterministic conditions and have no basis in risk, frequency is not assigned.

5.1.2 Event Selection

The first step toward LBE selection is to establish a complete set of events. This selection was aided by a systematic review of the following resources:

- Search over operating lifecycle, all sources of radioactivity, and the range of operating modes and conditions for the Oklo design,
- Review generic events to all nuclear reactors,
- Review metal-fueled fast reactor operating experience,
- Review compact reactor operating experience and analytical methods,
- Review light water reactor events, and
- Review expert opinion on similar conceptual designs.

All events that had a potential challenge to the reactor were included in the initial list of events. In the initial event selection step, there is no attempt to determine if an event was inside or outside of the design basis; this distinction is made later in the process.

5.1.3 Risk Analysis

Risk analysis was performed using a PRA, specifically by implementing dynamic PRA (DPRA). It is important to note that a DPRA dynamic event tree is also the actual safety code simulation. A distinction does not exist between performing safety analyses and constructing probabilistic branching event sequences: both are done simultaneously, in a single analysis step. The DPRA is shown in Section 4.

5.1.4 Event Categorization and Selection of Bounding Events

Abnormal events in the Oklo reactor generally arise from an imbalance between heat generation and heat removal. This imbalance can occur due to either an increase or decrease in heat generation or an increase or decrease in heat removal, in each case causing a departure from nominal steady-state operation.

The resulting broad initial categories considered for the Oklo LBE analysis are the following:

- Reactivity insertion,
- Loss of cooling,
- Loss of heat sink, and

- Overcooling.

These initial event categories are briefly discussed below to describe the bounding events selected for this analysis.

5.1.4.1 Reactivity Insertion

[redacted]

[redacted]}{(i)-(xi)}{eci} The transient overpower event is the bounding case for the surplus heat generation case and is discussed further in this report.

Negative reactivity insertion events{[redacted]}{(i)-(xi)}{eci} result in lower peak fuel temperatures than the bounding positive reactivity insertion transient overpower event and as such are not discussed further in this report.

5.1.4.2 Loss of Cooling

A loss of cooling in the Oklo design primarily involves some variation of loss of the heat pipes since they are the mechanisms that transport heat away from the core. [redacted]{(i)-(xi)}{eci} In the Oklo LBE analysis, loss of cooling is not analyzed as a stand-alone LBE but is analyzed through the loss of heat sink events.

The loss of cooling events are essentially equivalent to the loss of heat sink events because the power conversion system is the only credited system to remove heat during normal operations. For purposes of this preliminary analysis, the decrease of heat removal event is the bounding event for the decrease of heat removal case, which includes the loss of cooling category.

---

15 [redacted]{(i)-(xi)}{eci}

5.1.4.3 Loss of Heat Sink

A loss of heat sink in the traditional sense, when applied to the Oklo design, would result in a loss of the power conversion system or its subsystems to some extent. Some examples include a turbine trip, an inadvertent opening of a turbine valve, a leak on a micro-level on the power conversion system side, and a small piping break on the power conversion system side. As discussed previously, the loss of heat sink events are analyzed together with the loss of cooling events and genericized to the decrease of heat removal events.

5.1.4.4 Overcooling

Overcooling events for the Oklo reactor involve a failure of the power conversion system that results in an excess removal of heat from the reactor. Through sensitivity studies, the overcooling category of events resulted in peak fuel temperatures below nominal and are therefore bounded by the decrease of heat removal event.

5.1.4.5 Summary of Bounding Events

The two bounding events for the Oklo design are transient overpower, for the surplus heat generation case, and decrease of heat removal. These events and their subsequent event sequences are detailed in the following sections.

Sequences resulting in frequencies under the LMP cutoff are not discussed in this section. For the Oklo analysis, this results in the exclusion of events with frequencies smaller than 10^{-7}/reactor-year, which is directly from the LMP guidance [25].

5.1.4.5.1 Transient Overpower

Transient overpower is analyzed in Section 4.3.1 and is determined to have three event sequences within the frequency cutoff. {

Table 5-2. [redacted]

[redacted]

}{(i)-(xi)}{eci}

5.1.4.5.2 Decrease of Heat Removal

Decrease of heat removal is analyzed in Section 4.3.2 and is determined to have two sequences within the frequency cutoff, as shown in Table 5-3.

Table 5-3. Decrease of heat removal sequences

Name	Description	Event Sequence Frequency (1/reactor-year)
Minor decrease of heat removal	Turbine trip, turbine bypass functional with 95% heat removal via power conversion system	9.98E-01
Protected major decrease of heat removal	Turbine trip, turbine bypass nonfunctional with 0% heat removal via power conversion system, with a reactor trip	2.00E-03

5.1.5 Analysis of Events Against the Frequency-Consequence Target

5.1.5.1 Background and Applied Considerations

The frequency-consequence target (F-C target) is replicated in Figure 5-1 [25]. The x-axis is adjusted from the LMP guidance to be linear.

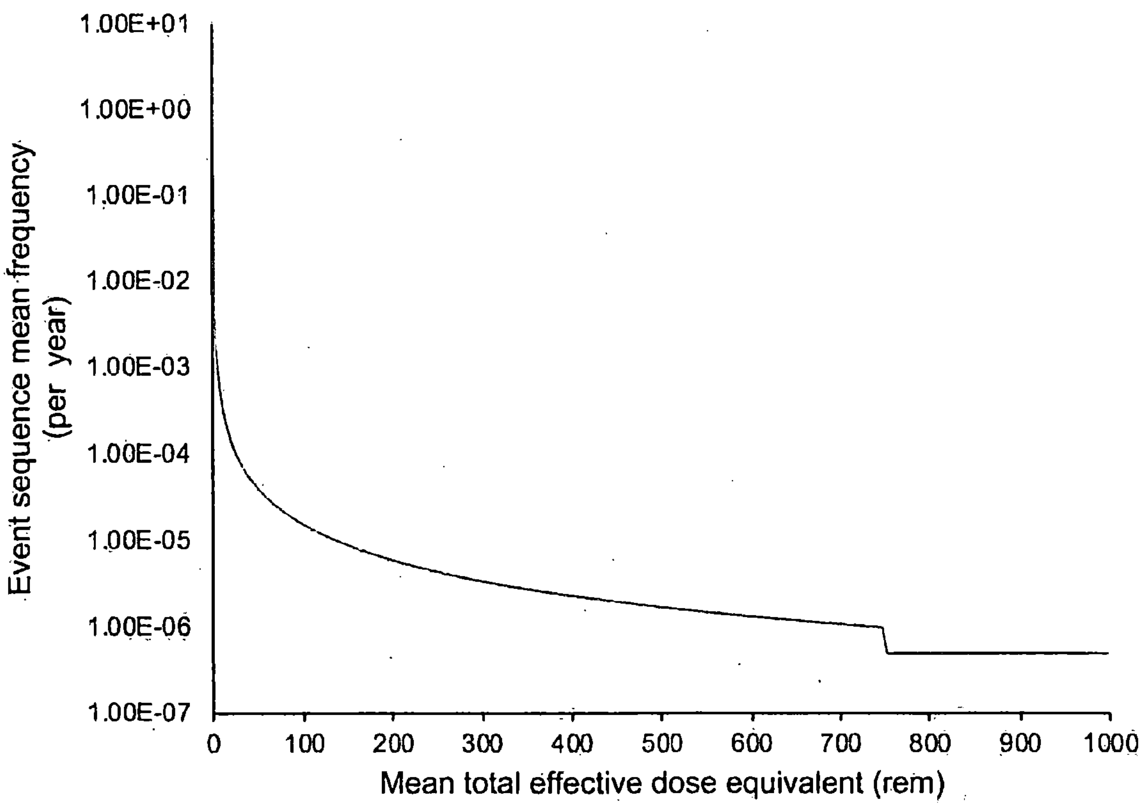

Figure 5-1. Frequency consequence target

It is important to note that the LMP guidance intends the F-C target to be used as a guide, instead of as a strict limit, stated as follows [25]:

The figure does not define specific acceptance criteria for the analysis of LBEs but rather a tool to focus the attention of the designer and those reviewing the design and related operational programs to the most significant events and possible means to address those events.

The selected frequency-consequence categories applied to the Oklo design LBE selection process are replicated in Table 5-4; the selected categories are largely consistent with the LMP guidance.

Table 5-4. Selected frequency-consequence categories for licensing basis events

Licensing Basis Event	Frequency (per reactor-year)	Dose (rem)	Source
Anticipated operational occurrence	1.00E-01	0.1	10 CFR 20.1301
	1.00E-02	1	PAG [a]
Design basis event	1.00E-02	1	PAG [a]
	1.00E-04	25	10 CFR 50.34
Beyond design basis event	1.00E-04	25	10 CFR 50.34
	1.00E-06	750	DG-1353
	5.00E-07	750	DG-1353

[a] The "PAG" refer to the Environmental Protection Agency's Protective Action Guides.

5.1.5.2 Methodology

5.1.5.2.1 Overview

The basic process followed to analyze events against the F-C target starts with the results obtained from the DPRA analysis in Section 4. These results include final core state conditions similar to those obtained from a traditional Level 1 PRA, except that instead of Boolean result states of "OK" or "CORE DAMAGE," the actual core conditions of fuel temperature and power are included. The estimated frequency of occurrence for each event sequence is also obtained, based on the initiating event frequencies and SSC failure probabilities.

The resulting core conditions are then used in a failure analysis to determine the consequences of each event sequence. The estimated consequences of each event sequence are plotted against their respective frequencies on the F-C curve.

5.1.5.2.2 Event Sequence Frequency Determination

Event sequence frequencies are estimated with DPRA. [redacted] (i)

[redacted]

(xi)}{eci} The DPRA tool used to drive the entire process is ADAPT, developed by Sandia National Laboratory [23]. The frequencies for the four analyzed event sequences are shown in Table 5-2 and Table 5-3.

5.1.5.2.3 Consequence Analysis

[redacted]

[redacted]

Figure 5-2. [redacted]

}{(i)-(xi)}{eci} Final temperatures for the analyzed transient overpower and decrease of heat removal events are not expected to remain high enough for damage to begin. [redacted]

Table 5-5. [redacted]

[redacted]

[redacted]}{(i)-(xi)}{eci} Therefore, for the risk-informed portion of the LMP process, no dose consequences are expected as a result. {

5.1.5.3 [redacted]

[redacted]

[redacted]

Figure 5-3. [redacted]

}{(i)-(xi)}{eci}

5.1.6 Analysis of Events Against the Integrated Risk Targets

In addition to comparing the LBE to the F-C target, an integrated risk evaluation of the Oklo plant as a whole is performed using the criteria informed by the LMP and replicated below.

The integrated risk of an entire Oklo plant is evaluated against three cumulative risk targets:

1. The total frequency of exceeding a site boundary dose of 100 mrem from all LBEs shall not exceed 1/reactor-year[17].

2. The average individual risk of early fatality within one mile of the exclusion area boundary (EAB) shall not exceed 5×10^{-7}/reactor-year to ensure that the Commission safety goal qualitative health objective (QHO) for early fatality risk is met.

[17] The guidance in the LMP explains that this metric is introduced to ensure that the consequences from the entire range of LBEs from higher frequency, lower consequences to lower frequency, higher consequences are considered. The value of 100 millirem is selected from the annual exposure limits in 10 CFR Part 20, "Standard for protection against radiation."

3. The average individual risk of latent cancer fatalities within 10 miles of the EAB shall not exceed 2×10^{-6}/reactor-year to ensure that the Commission safety goal QHO for latent cancer fatality risk is met.

5.1.6.1 First Integrated Risk Target

No risk-informed LBEs (shown in Figure 5-3) exceed a site boundary dose of 100 mrem, therefore this target is met by default.

5.1.6.2 Second Integrated Risk Target

No risk-informed LBEs (shown in Figure 5-3) are shown to have any site boundary dose, therefore this target is met by default.

5.1.6.3 Third Integrated Risk Target

No risk-informed LBEs (shown in Figure 5-3) are shown to have any site boundary dose, therefore this target is met by default.

5.1.7 Design Basis Accident Analysis

5.1.7.1 Overview

The LMP guidance requires the deterministic evaluation of design basis accidents (DBAs). For the Oklo LBEs, this is required for the two DBEs [redacted]}{(i)-(xi)}{eci}. For this analysis, all active components are assumed to fail. [redacted]}{(i)-(xi)}{eci} Passive components such as barriers to radionuclide release are assumed to be present but to have no leak tight capability; this is accomplished by using an conservatively large leak rate.

As a first step in analyzing these DBAs, the deterministic active SSC failures mentioned above are applied to the two DBEs. [redacted]{(i)-(xi)}{eci} As the unprotected combined overpower and loss of cooling accident bounds the unprotected loss of cooling-only accident, the remainder of this DBA analysis will focus on this combined accident.

The accident analysis begins by simulating the core transient response to the deterministic initiating event. The resulting peak temperature and power from the transient are then used to estimate the [redacted]}{(i)-(xi)}{eci} inventory of radionuclides exposed to a release pathway.

These available radionuclides are then applied to an estimated dose analysis. The dose analysis consists of several steps, beginning with the identification of the dose-significant nuclides present in the core inventory and their associated activities. This is followed by an estimation of the fraction of radionuclides expected to be released from the fuel and a subsequent release pathway analysis to determine the fraction of radionuclides that escape to the environment. Finally, atmospheric dispersion models are applied to obtain a resulting dose estimate at the site boundary. Each step in this process is more fully described in the following sections.

5.1.7.2 Transient Analysis

The combined unprotected transient overpower and loss of cooling DBA is initiated at 10 seconds. [redacted] {(i)-(xi)}{eci} Fuel temperature increases due both to the power increase as well as the loss of cooling. After 30 seconds, the inherent negative reactivity addition from increasing fuel temperature due to the negative net temperature feedback coefficient of reactivity exceeds the positive reactivity addition [redacted] {(i)-(xi)}{eci}

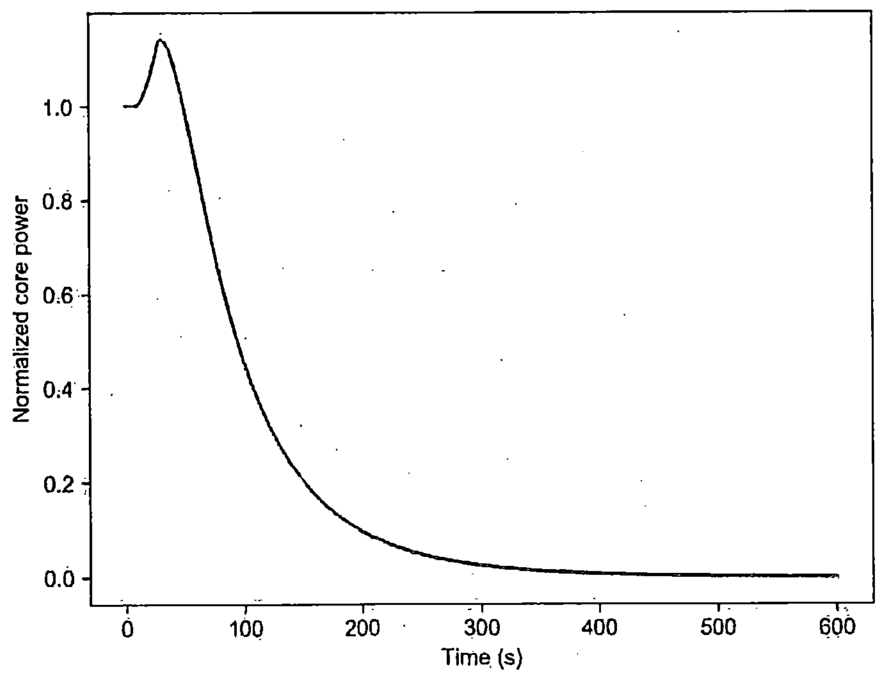

Figure 5-4. Normalized power versus time during the combined unprotected transient overpower and loss of cooling design basis accident

{

18 [redacted]

[redacted]

Figure 5-5. [redacted]

5.1.7.3 [redacted]

[redacted]

[redacted]

Figure 5-6: [redacted]

[redacted]

Table 5-6. [redacted]

[redacted]

[redacted]}{(i)-(xi)}{eci}

5.1.7.4 Dose Analysis

5.1.7.4.1 Dose-Significant Isotopes

The results discussed in this report are from the MELCOR Accident Consequence Code System (MACCS) and correspond to a radiological dose at 100 m following a scenario involving fission product release [redacted]}{(i)-(xi)}{eci}. It is important to note that for purposes of this pilot submittal, a Level 1 PRA, as derived by the DPRA, is used in conjunction with a simple dose calculation, as produced by MACCS; this approach is consistent with current and prior LMP guidance.

Since only certain radionuclides are significant in a source term analysis, those radionuclides of interest were utilized in the dose analysis. The radionuclides of interest were determined from a report on source term methodology conducted by Argonne National Laboratory (ANL) and Sandia National Laboratory [26]. The study calculated importance weights for each radionuclide by simulating a direct release of a large quantity (10^8 Curies) of each radionuclide. This simulation was done using the RASCAL code and calculated the contributions of each nuclide to the estimated inhalation and immersion (cloudshine) dose. The most important dose contributors were then selected from this weighted list of nuclides and are reported in Table 5-7.

Table 5-7. Dose-contributing isotopes [26]

Am-241	Cs-137	Kr-88	Pu-241	Sr-91	Xe-135
Am-242	I-131	La-140	Rb-86	Sr-92	Xe-135m
Ba-139	I-132	La-141	Rh-105	Tc-99m	Xe-138
Ba-140	I-133	La-142	Ru-103	Te-129	Y-90
Ce-141	I-134	Mo-99	Ru-105	Te-129m	Y-91
Ce-143	I-135	Nb-95	Ru-106	Te-131m	Y-92
Ce-144	Kr-83m	Nd-147	Sb-127	Te-132	Y-93
Cm-242	Kr-85	Np-239	Sb-129	Xe-131m	Zr-95

Cs-134	Kr-85m	Pr-143	Sr-89	Xe-133	Zr-97
Cs-136	Kr-87	Pu-238	Sr-90	Xe-133m	

5.1.7.4.2 Radionuclide Inventory Activity

Activity is determined by multiplying specific activity by the mass of isotope present. Specific activity values were determined analytically from half-life values provided by MACCS input files in conjunction with the atomic weight of each nuclide. The masses of radiologically-significant isotopes present were extracted from a spent fuel vector generated by a depletion calculation performed by the Serpent Monte Carlo neutron transport code; this spent fuel vector demonstrates a conservative end-of-life fuel inventory. This is a conservative inventory because it is calculated over a fuel cycle life that is 50% longer than the anticipated cycle length to cover uncertainties.

5.1.7.4.3 Radioisotope Release Fractions from the Fuel Matrix

Full fission gas release (i.e., fission gas escaping the fuel matrix) occurs in fuel where porosity reaches values above 20%[19]. [redacted] {(i)-(xi)}{eci}

By analyzing data from fuel pins irradiated in EBR-II, ANL obtained elemental release fractions for fuel at burnups where full fission gas release has not yet occurred. [redacted]

Table 5-8. [redacted]

[redacted]

[19] Numerous case studies performed by INL estimate that fission gas release in sodium fast reactors is expected when fuel porosity reached 24-25%

[redacted]

}{(i)-(xi)}{eci}

5.1.7.4.4 Release Pathway Calculations

[redacted]}{(i)-(xi)}{eci}

A generic four compartment model, as shown in Figure 5-7, is used to estimate leakage through three physical barriers. [redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]}{(i)-(xi)}{eci}

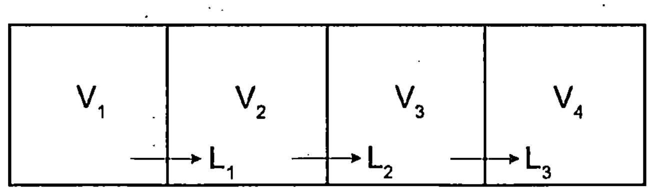

Figure 5-7. Generic compartment model

The leak rates assumed throughout this analysis are 1 mass %/day, which is extremely conservative for two reasons. A leak rate of 1 mass %/day is several orders of magnitude larger

than typically assumed for similarly sized reactors[20]. Additionally, a mass leak rate is a more conservative estimate than a volume leak rate because it disregards mixing and pressure differentials that would occur in the reactor enclosures plena. The assumption of such high leak rates shows that no credit is being taken for these barriers to be leak tight. Since these barriers are physical structures, their presence is still modeled with these conservative leak fractions. [redacted] }{(i)-(xi)}{eci}

The numerical models describing the transfer of nuclides over time from the starting compartment to subsequent compartments are shown in differential form in the below equations. It is important to note that these equations do not account for decay during the compartment-to-compartment transfer process. Since radioactive decay is a reduction in isotope mass, this exclusion is conservative.

Equation 2. Generic differential equation for first volume

$$\frac{dM_1}{dt} = -L_1 M_1$$

Equation 3. Generic differential equation for second volume

$$\frac{dM_2}{dt} = -L_2 M_2 + L_1 M_1$$

Equation 4. Generic differential equation for third volume

$$\frac{dM_3}{dt} = -L_3 M_3 + L_2 M_2$$

Equation 5. Generic differential equation for fourth volume

$$\frac{dM_4}{dt} = L_3 M_3$$

$$where,$$

$$M_1 = radionuclide\ mass\ in\ the\ first\ volume, V_1\ (g)$$

$$M_2 = radionuclide\ mass\ in\ the\ second\ volume, V_2\ (g)$$

$$M_3 = radionuclide\ mass\ in\ the\ third\ volume, V_3\ (g)$$

$$M_4 = radionuclide\ mass\ in\ the\ fourth\ volume, V_4\ (g)$$

$$L_1 = mass\ leak\ rate\ from\ the\ first\ volume, V_1, into\ the\ second\ volume, V_2\ (s^{-1})$$

$$L_2 = mass\ leak\ rate\ from\ the\ second\ volume, V_2, into\ the\ third\ volume, V_3\ (s^{-1})$$

$$L_3 = mass\ leak\ rate\ from\ the\ third\ volume, V_3, into\ the\ fourth\ volume, V_4\ (s^{-1})$$

[20] Leak rates for the confinements used in nonpower reactors that have a thermal power rating an order of magnitude larger than the Oklo reactor are on the order of 10^{-3} volume %/day.

5.1.7.4.5 Atmospheric Conditions and Breathing Rate

Constant weather conditions were assumed in MACCS with inputs that influence atmospheric dispersion factors, $\frac{X}{Q}$, to be the most conservative. Conservative values were those values that would produce the largest site boundary dose. For example, the release was assumed to be a ground release with stable atmospheric conditions, Pasquill wind stability class 'F', and minimal wind speeds of 1 m/s. Finally, a breathing rate of $3.5 \times 10^{-4} \frac{m^3}{s}$ was assumed [27].

5.1.7.4.6 Dose Conversion Factors

The dose conversion factors are typically obtained from the Environmental Protection Agency Federal Guidance Reports No. 11, "Limiting Values of Radionuclide Intake and Air Concentration and Dose Conversion Factors for Inhalation, Submersion, and Ingestion," and No. 12, "External Exposure to Radionuclides in Air, Water, and Soil."

5.1.7.4.7 Daughter Products

In MACCS, daughter decay after release to the environment is accounted for six generations before losing significance. For this analysis, all daughters were considered significant. This is an overly conservative decision as not all daughter products carry dose implications.

5.1.7.4.8 Calculation of Total Effective Dose Equivalent

It is important to note that since the goal of the MACCS calculations was to estimate total effective dose equivalent (TEDE) at a set distance, only effective dose equivalent (EDE) and committed effective dose equivalent (CEDE) were calculated. This means that shielding factors were set in MACCS in such a way to provide complete protection from incurred dose to the skin and from groundshine.

MACCS was used to perform a preliminary two hour dose estimate for an Oklo reactor [redacted] }(i)-(xi)} at a 100 m site boundary; this is an appropriate analysis because it is consistent with analysis that should be performed for DBAs [25]. This dose estimation was calculated by modeling a single non-evacuating, relocating cohort. Normal and hotspot relocation was enabled after two hours, assuming a zero-threshold dose. [redacted] }(i)-(xi)} The peak dose is well within the acceptable limits for a DBA, as defined in the LMP and 10 CFR 50.34, "Contents of applications; technical information," and 10 CFR Part 100, "Reactor site criteria."

The summary of inputs and conservative assumptions is shown in Table 5-9.

Table 5-9. Result and conservatisms for deterministic dose analysis

Assumption in Analysis	Implication
[redacted]	[redacted] }(i)-(xi)}(eci}
Spent fuel vector is 50% longer than anticipated cycle length	Overly conservative radionuclide inventory
Leakage of 1 mass %/day	Barriers are not leak tight
No radioactive decay during leakage	Overly conservative radionuclide inventory
All daughter products considered significant	Overly conservative radionuclide inventory

Use of release fractions at higher burnup	Overly conservative radionuclide inventory
Pasquill wind stability class F	Overly conservative atmospheric dispersion
High breathing rate	Overly conservative dose
Release assumed to be ground release	Overly conservative dose
Wind speed is lowest possible	Overly conservative dose
Distance:	100 m
{[redacted]	[redacted]}{(i)-(xi)}

5.1.8 Safety Functions

The top safety goal of the Oklo reactor is to minimize the risk to the public and the environment by controlling dose. Dose is determined by the total amount of radionuclides released and the atmospheric dispersion parameters. Because the latter is influenced by conditions external to the Oklo reactor, the safety goal of the Oklo reactor is to control the former. [redacted]}{(i)-(xi)}{eci}

Events for the LBE selection process are identified if they challenge the safety function. From the preceding evaluation against the F-C target, the bounding Oklo risk-informed LBEs are not shown to come within a range considered challenging to the reactor. For the DBA analysis, the identified DBA results in a dose within the regulatory limits. Since all active SSCs are assumed to fail for this DBA analysis, there are no identified safety functions.

5.2 Safety Classification and Performance Criteria for Structures, Systems, and Components

5.2.1 Overview of Methodology

The SSC safety classification process classifies SSCs on the basis of the SSC safety functions reflected in the LBEs. Although the SSCs are classified, the resulting performance and special treatment requirements are for the specific functions identified in the LBEs. This process is described as an SSC function classification process rather than an SSC classification process because only those SSCs whose functions prevent or mitigate accidents represented in the LBEs are of concern. A given SSC may perform other functions that are not relevant to LBE prevention or mitigation or perform functions with a different safety classification. The Oklo LBE selection process is a modified process that is based on the steps outlined in Figure 4-1 of the LMP guidance [25] and includes the following steps:

1. Determination of required and safety-significant functions,
2. Determination of SSCs to perform safety-significant functions,
3. Classification of SSCs,
4. Determination of reliability and capability requirements, and
5. Determination of SSC design criteria and special treatment requirements.

Definitions for "safety-significant," "risk-significant," "safety-related," "nonsafety-related with special treatment (NSRST)," and "nonsafety-related with no special treatment (NST)" are informed by the LMP guidance and shown in Table 5-10; these definitions are identical to the LMP guidance [25]. For this pilot, "important to safety" has been taken to be items which are either safety-related or special treatment, that is, items which are risk-significant or have identified to be important to defense-in-depth. This definition of items important to safety is essentially what is defined in the LMP guidance as safety-significant. The definition of important to safety is useful for the portions of the pilot which have to do with the interpretation of application requirements such as 52.79(a)(10), "Electrical Equipment Important to Safety," and 52.79(a)(11), with regard to 50.55a(e), "Quality Group C Components."

Table 5-10. Definition of classification terms

Safety-Significant	Safety-related	SSCs selected by the designer from the SSCs that are available to perform the required safety functions to mitigate the consequences of DBEs and BDBEs to within the LBE F-C target. SSCs selected by the designer and relied on to perform required safety functions for DBAs with consequences greater than the 10 CFR 50.34 dose limits.
	Nonsafety-related with special treatment	Nonsafety-related SSCs relied on to perform risk-significant functions. Risk-significant SSCs are those that perform functions that prevent or mitigate any LBE from exceeding the F-C target or make significant contributions to the cumulative risk metrics selected for evaluating the total risk from all analyzed LBEs. Non-safety-related SSCs relied on to perform functions requiring special treatment for DID adequacy.
Not Safety-Significant	Nonsafety-related with no special treatment	All other SSCs (with no special treatment required).

5.2.2 Determination of Required and Safety-Significant Functions

The purpose of this task is to define the safety functions that are required to meet the 10 CFR 50.34 dose requirements for all the DBAs as well as other safety functions regarded as safety-significant.

5.2.2.1 Determination of Required Safety Functions

The LMP guidance defines "required safety functions" as those that are necessary to meet the following two criteria:

1. Ensure that the LBEs meet the F-C target requirements, and
2. Ensure that the dose requirements are met for DBAs.

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

5.2.2.2 Determination of Safety-Significant Functions

The LMP guidance discusses that there may be additional functions that are classified as safety-significant if necessary to meet certain risk-significant functions. The LMP guidance states, "A risk significant SSC function is one that is necessary to keep one or more LBEs within the F-C Target or is significant in relation to one of the LBE cumulative evaluation risk metric limits." [25]

Risk is determined by frequency multiplied by consequence. [redacted]

5.2.3 [redacted]

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

5.2.4 Classification of SSCs

5.2.4.1 Seismic Considerations

The criteria for the plant design bases that demonstrate the capability for SSCs to function during and after vibratory ground motion associated with the safe shutdown earthquake (SSE) are located in Appendix A, "Seismic and geologic siting criteria for nuclear power plants," to 10 CFR Part 100. The SSE is defined as the maximum potential vibratory ground motion at the generic plant site. Seismic evaluation is outside the scope of this pilot, however, a tentative evaluation of seismic classification of SSCs is provided to more fully pilot the guidance and to show implications of safety classification of SSCs for other portions of an application. The seismic classification first look contained in this document is partially consistent with Regulatory Guide (RG) 1.29, "Seismic Design Classification for Nuclear Power Plants," Revision 5. Because the Oklo design is simple, SSCs are categorized as Category I seismic or Category II non-seismic. Category I SSCs are those SSCs that retain their integrity and functionality during the SSE, whereas seismic Category II SSCs are those SSCs that retain only their integrity during the SSE. Generally, Category I SSCs are safety-related or have functions that support or protect safety-related SSCs. Category II seismic SSCs are those SSCs that are non-seismic; this category applies to SSCs that do not have a safety-related function but that are designed to withstand an SSE without collapse. However, further seismic analysis will be performed and assessments will be revisited using seismic analysis information.

Seismic events have traditionally been considered the most bounding external events for metal-fueled fast reactors, primarily due to the possibility of large induced positive reactivity insertions caused by control rod motion relative to the core lattice [19]. The Oklo design is resilient to this concern [redacted]}{(i)-(xi)}{eci} However, this presupposition will likely be confirmed via additional analysis. Additionally, a primary concern in seismic analysis for most reactor design types is "sloshing" or the movement of fluid volumes. Because the Oklo reactor has no significant fluid

volumes, this concern is essentially negated. Again, further analysis will be performed to demonstrate this phenomenon.

5.2.4.2 Quality Assurance Considerations

Safety-related SSCs have specific requirements described in Appendix B, "Quality assurance criteria for nuclear power plants and fuel reprocessing plants," to 10 CFR Part 50. Any SSCs identified as safety-related for the Oklo design would fall under this requirement. It is important to note that the Oklo quality assurance program will have other performance-driven requirements that are not directly required by the regulations.

5.2.4.3 Decay Heat Removal Considerations

The Oklo design includes a system that removes appropriate amount of decay heat after reactor shutdown to maintain the integrity of the NST components for investment protection reasons. For the Oklo preliminary safety analysis that is outlined in this report, this system is not assumed to function or even exist. [redacted]

5.2.4.4 [redacted]

[redacted]

5.2.4.5 [redacted]

[redacted]

5.2.4.6 [redacted]

[redacted]

5.2.4.7 [redacted]

[redacted]

Table 5-11. [redacted]

[redacted]

[redacted]

5.2.5 [redacted]

[redacted]}{(i)-(xi)}{eci}

5.2.6 Determination of Design Criteria and Special Treatment Requirements

[redacted]{(ii)-(iv), (vi), (ix)-(xi)}

The Oklo design does not credit any barriers as safety-related fission product retention barriers. This is reflected through the analysis as the barriers are assumed to leak significantly (i.e., to not be leak tight).

5.3 Evaluation of Defense-in-Depth Adequacy

5.3.1 Purpose and Scope

The LMP guidance calls for an evaluation of the adequacy of a design's defense-in-depth. The LMP guidance broadly defines defense-in-depth using the NRC glossary's definition: "an approach to designing and operating nuclear facilities that prevents and mitigates accidents that release radiation or hazardous materials. The key is creating multiple independent and redundant layers of defense to compensate for potential human and mechanical failures so that no single layer, no matter how robust, is exclusively relied upon." The LMP guidance states that, presently, defense-in-depth has been "defined primarily as a general philosophy by the NRC."

Oklo applied the sections of the LMP guidance that were found to be implementable or relevant to the Oklo design. Where difficulties in applying the guidance were encountered, a discussion surrounding those difficulties is presented. As with the rest of Section 5, the evaluation of defense-in-depth adequacy was performed only considering normal operations.

5.3.2 Overview of Licensing Modernization Project Defense-in-Depth Evaluation Guidance

The LMP guidance's framework for establishing defense-in-depth adequacy is shown in Figure 5-8, which is presented unchanged from Figure 5-2 in the LMP guidance document.

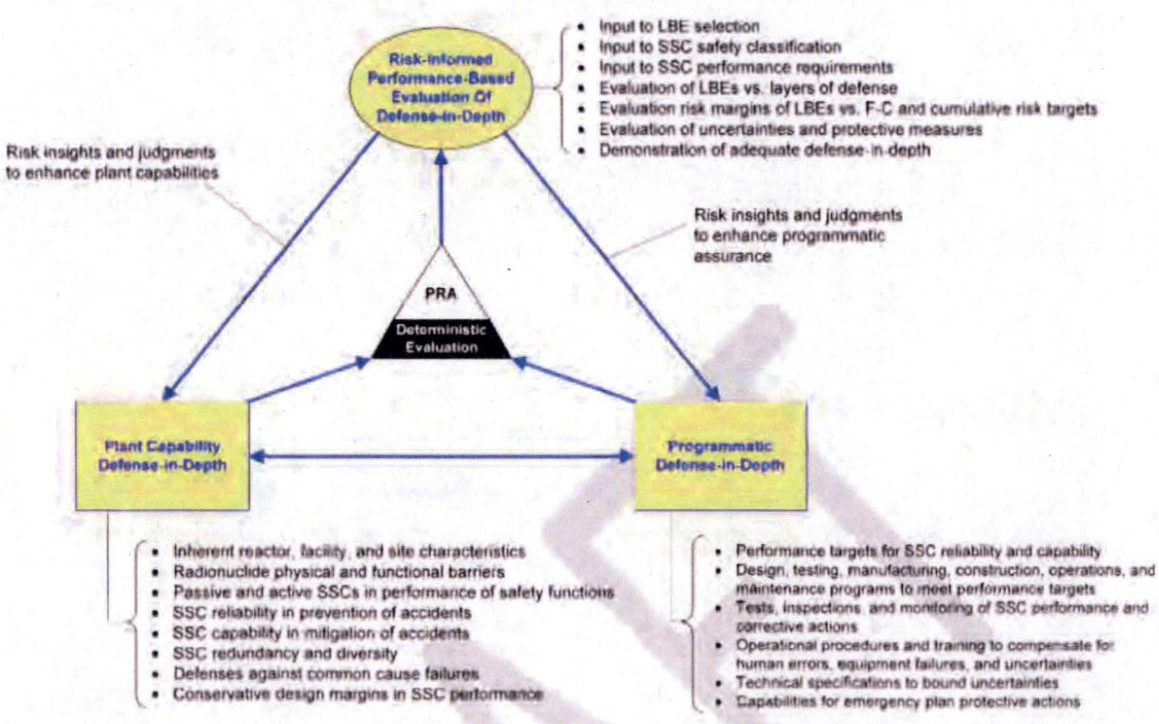

Figure 5-8. Framework for establishing defense-in-depth adequacy using the Licensing Modernization Project guidance

The framework consists of three primary components for establishing adequacy (depicted as yellow bubbles in Figure 5-8). The components are:

(1) Establishing the adequacy of plant capability defense-in-depth,

(2) Establishing the adequacy of programmatic defense-in-depth, and

(3) Risk-informed performance-based evaluation of defense-in-depth adequacy.

Plant capability defense-in-depth includes functions, SSCs, and bounding design capabilities to assure safety adequacy. It can be divided into two categories: 1) plant functional capability defense-in-depth, and 2) plant physical capability defense-in-depth. Plant functional capability defense-in-depth is achieved through systems and features designed to prevent occurrence of LBEs or mitigate their consequences. Plant physical capability defense-in-depth is introduced through SSC robustness and physical barriers to limit the consequences of a hazard.

Programmatic defense-in-depth is where programmatic protective strategies are defined. It is used to identify and incorporate any special treatments that may be necessary during any phase of the design, construction, or operation of the plant. These special treatments may be used to compensate for uncertainties in plant capability defense-in-depth, as appropriate.

The risk-informed performance-based evaluation of defense-in-depth adequacy is meant to provide a systematic and comprehensive process for holistically evaluating the combined defense-in-depth adequacy achieved by the plant capability and programmatic defense-in-depth elements. A key component in performing this holistic assessment is evaluating each LBE against the "layers of defense," a concept originally proposed by the IAEA for ensuring defense-in-depth protection at nuclear power plants and now incorporated into the LMP [28]. Additionally, examining the questions posed by the risk triplet, performing a state of knowledge characterization, determining the adequacy of safety and performance margins, and understanding the sources and magnitude of uncertainties all play a role in the risk-informed performance-based evaluation of defense-in-depth adequacy.

Oklo's approach to implementing the LMP guidance for each of these components is described in subsequent sections. However, a note of clarification on the evaluation of LBEs against the Layers of Defense is necessary here. This evaluation is initially grouped with the risk-informed performance-based evaluation of defense-in-depth in the LMP guidance, as depicted in Figure 5-8. However, rather than being discussed in the LMP guidance document's Section 5.9, "Risk-informed and Performance-Based Evaluation of DID Adequacy," it is instead described in most detail in Figure 5-3 of the LMP guidance document, where an overview of each of the LMP defense-in-depth components is presented. A separate section on "Evaluation of LBEs Against the Layers of Defense," numbered as Section 5.7 in the LMP guidance document, discusses objectives for the evaluation but references neither the process presented in Figure 5-3 of the LMP guidance document, nor the considerations presented in Section 5.9 of the LMP guidance document. Furthermore, Section 5.6 of the LMP guidance document, "Establishing the Adequacy of Plant Capability DID," provides a table outlining the Layers of Defense and the guidelines for determining whether defense-in-depth adequacy has been achieved for each layer and cumulatively over all layers.

As a result, the process for performing the evaluation of LBEs against the Layers of Defense is somewhat unclear, as is the appropriate place for presentation of the obtained conclusions. Oklo has taken the approach of applying the process outlined in Figure 5-3 of the LMP guidance

document, and evaluating it against the criteria outlined in Section 5.6 of the LMP guidance document to determine adequacy of plant capability defense-in-depth. Accordingly, the evaluation and the plant capability adequacy determinations are presented in this report together, in Section 5.3.3, Establishing the Adequacy of Plant Capability Defense-in-Depth.

In the defense-in-depth LMP guidance, these components are to be evaluated by a panel of experts appointed by the applicant, known as the Integrated Decision Panel (IDP). The LMP uses the guidance in NEI 00-04, "10 CFR 50.69 SSC Categorization Guideline," as a basis for the composition of this panel [29]. NEI 00-04 recommends that the panel should be comprised of at least five members, with joint expertise in the following fields:

(1) Plant operations (SRO qualified),

(2) Design engineering,

(3) Safety analysis,

(4) Systems engineering, and

(5) Probabilistic risk assessment.

Since NEI 00-04 was originally intended to apply to the recategorization of SSCs of operating commercial nuclear power plants using a risk-informed process, these categories are less directly translatable to advanced reactors. In particular, experts with experience in plant operations who possess SRO qualifications for a non-LWR reactor are unlikely to exist at the time an application is submitted to the NRC for review of an advanced non-LWR reactor. [redacted] {(ii)-(iv), (vi), (ix)-(xi)} The defense-in-depth aspects of the Oklo reactor will accordingly be evaluated in a collaborative peer-review fashion by Oklo engineers who have performed the design, safety analysis, systems development, and probabilistic risk assessment, all following the standard Oklo quality assurance program.

5.3.3 Establishing the Adequacy of Plant Capability Defense-in-Depth

5.3.3.1 Introduction to the Layers of Defense Concept

The guidelines for establishing adequacy of plant capability defense-in-depth are evaluated against the five "Layers of Defense," a concept originally introduced by the IAEA and incorporated into the LMP. Each layer describes objectives and success conditions associated with preventing, controlling, or mitigating LBEs in categories of increasing severity. Thus, Layer 1 treats small disturbances or transients, Layer 2 treats Anticipated Operational Occurrences (AOOs), Layer 3 treats Design Basis Events, Layer 4 treats Beyond Design Basis Events, and Layer 5 treats severe accidents with significant releases of radioactive materials. A visual depiction of the Layers of Defense, including each layer's objectives and success criteria, arranged in a flow chart illustrating the evaluation process of LBEs against the layers, is duplicated from the LBE guidance document and shown in Figure 5-9.

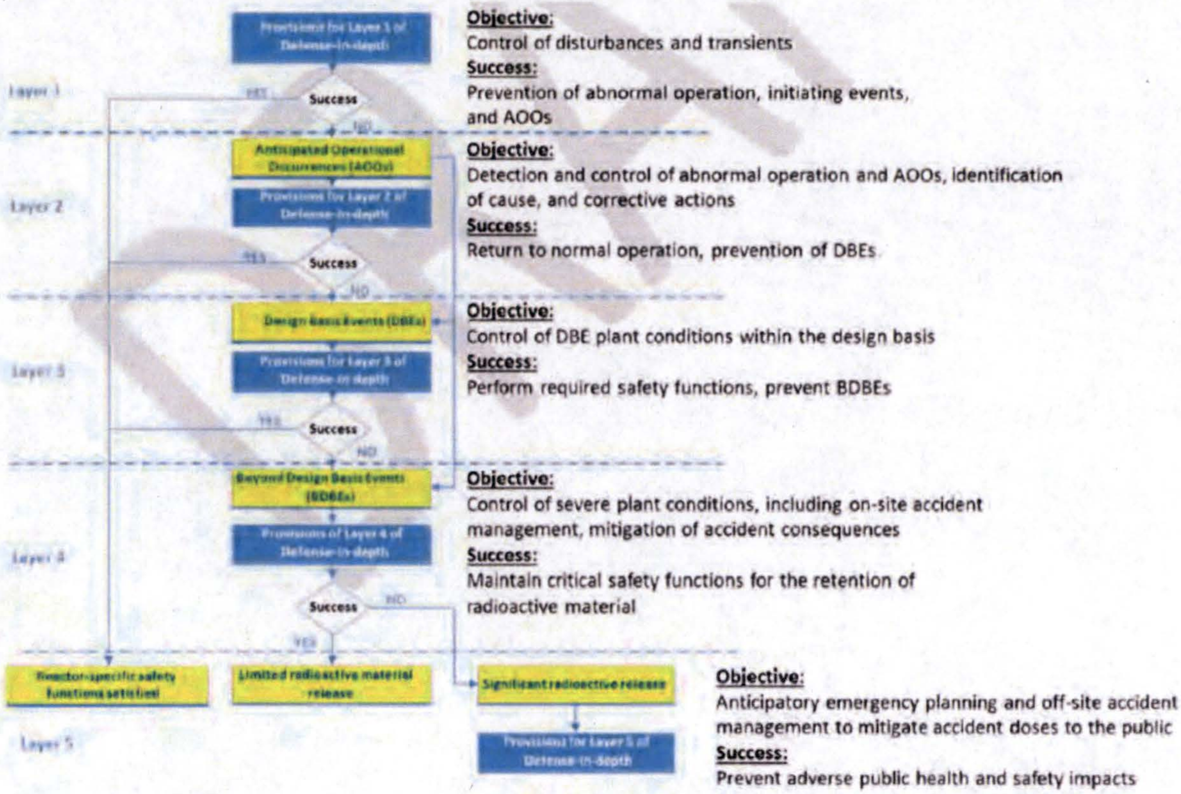

Figure 5-9. Process for evaluating licensing basis events using Layers of Defense under the Licensing Modernization Project guidance

Each layer of defense is associated with qualitative and quantitative guidelines that help to establish adequacy of plant capability defense-in-depth. Structures, systems, and components that help satisfy these guidelines can be considered as contributing to defense-in-depth. If satisfied, these individual layer guidelines, together with overall plant capability defense-in-depth guidelines that apply across all layers, form a basis for determining if the plant capability defense-in-depth is adequate. A presentation of the plant capability adequacy guidelines associated with each layer is duplicated from the LBE guidance document and shown in Table 5-12. A more complete description of each layer follows.

Table 5-12. Guidelines for establishing plant capability defense-in-depth adequacy using the Layers of Defense concept

Layer[a]	Layer Guideline		Overall Guidelines	
	Quantitative	Qualitative	Quantitative	Qualitative
1) Prevent off-normal operation and AOOs	Maintain frequency of plant transients within designed cycles; meet owner requirements for plant reliability and availability[b]		Meet F-C Target for all LBEs and cumulative risk metric targets with sufficient[d] margins	No single design or operational feature,[c] no matter how robust, is exclusively relied upon to satisfy the five layers of defense
2) Control abnormal operation, detect failures, and prevent DBEs	Maintain frequency of all DBEs $< 10^{-2}$/ plant-year	Minimize frequency of challenges to safety-related SSCs		
3) Control DBEs within the analyzed design basis conditions and prevent BDBEs	Maintain frequency of all BDBEs $< 10^{-4}$/ plant-year	No single design or operational feature[c] relied upon to meet quantitative objective for all DBEs		
4) Control severe plant conditions, mitigate consequences of BDBEs	Maintain individual risks from all LBEs < QHOs with sufficient[d] margins	No single barrier[e] or plant feature relied upon to limit releases in achieving quantitative objectives for all BDBEs		
5) Deploy adequate offsite protective actions and prevent adverse impact on public health and safety				

5.3.3.1.1 Layer of Defense 1: Control of Disturbances and Transients

The first layer of defense treats events of the lowest severity. The objective for provisions of Layer 1 is to control small plant disturbances and transients. Success in this objective results in prevention of off-normal operation and anticipated operational occurrences (AOOs).

The defense-in-depth adequacy guidelines for this layer are: 1) maintain frequency of plant transients within designed cycles, and 2) meet owner requirements for plant reliability and availability.

5.3.3.1.2 Layer of Defense 2: Control Abnormal Operation

The second layer of defense treats LBEs that fall into the AOO category. The objective of defense-in-depth Layer 2 is to detect and control AOOs, including identification of their cause and taking corrective actions. Successfully meeting this objective implies a return to normal operation and the prevention of design basis events.

This layer possesses both a quantitative guideline and a qualitative guideline for establishing plant capability defense-in-depth adequacy. The quantitative guideline is to maintain frequency of all DBEs at less than 1×10^{-2}/reactor-year.[21] The qualitative guideline is to minimize the frequency of challenges to safety-related SSCs.

[21] The LMP guidance uses "plant-year" while NRC regulations and guidance more typically use reactor-year. For the Oklo reactor, each plant only has one reactor, so the terms are interchangeable. For this pilot document, the term "reactor-year" was used for internal consistency as well as consistency with the NRC.

5.3.3.1.3 Layer of Defense 3: Control Design Basis Events within the Analyzed Design Basis Conditions

The objective of the third layer of defense is to control DBE plant conditions within the design basis. Successful operation in this layer occurs when required safety functions have been performed, and beyond design basis events are prevented.

The quantitative guideline for establishing plant capability adequacy for this layer is to maintain frequency of all BDBEs below 1×10^{-4}/reactor-year. The qualitative adequacy guideline is to ensure that no single design or operational feature is relied upon to meet the quantitative objective for all design basis events.

5.3.3.1.4 Layers of Defense 4: Control Severe Plant Conditions and Mitigate Consequences of BDBEs

The fourth layer of defense applies to BDBEs. This layer's objective is to control severe plant conditions and mitigate BDBE consequences. Successful operation of Layer 4 involves maintaining critical safety functions for the retention of radioactive material.

The quantitative guideline for establishing plant capability adequacy for this layer is that individual risks from all LBEs must be maintained at a value less than that of the Qualitative Health Outcomes (QHOs) with sufficient margins. The qualitative adequacy guideline is to ensure that no single barrier or plant feature is relied upon to limit releases in achieving the quantitative objectives for all BDBEs.

5.3.3.1.5 Layer of Defense 5: Mitigate Radiological Consequences of Significant Releases of Radiological Material

The fifth layer of defense applies to severe accidents where significant releases of radiological material occurs. The objective of Layer 5 is to mitigate accident doses to the public by employing anticipatory emergency planning and offsite accident management. Successful operation of this layer prevents adverse public health and safety impacts.

The quantitative and qualitative guidelines for establishing plant capability adequacy for this layer are identical to those of Layer 4: individual risks from all LBEs must be maintained below the QHO values, and no single barrier or plant feature should be relied upon to limit releases while seeking to minimize doses below these values.

Layer 5 is the last line of defense. It serves to ensure that even in the incredibly unlikely event of a severe accident, adverse impacts on public health and safety are still avoided. The entire evaluation of all layers of defense drives towards this goal: that public health and safety are protected.

5.3.3.1.6 Overall Guidelines for Plant Capability Defense-in-Depth Adequacy

In addition to the layer-specific guidelines for determining plant capability defense-in-depth adequacy, one quantitative guideline and one qualitative guideline are applied comprehensively across layers, as shown in Table 5-12. The overall quantitative guideline is to have sufficient margins to the F-C target for all LBEs and cumulative risk metric targets. The overall qualitative guideline is to ensure that no single design or operational feature, no matter how robust, is exclusively relied upon to satisfy the layers of defense. These overall guidelines help

to provide perspective on how the Layers of Defense operate as a whole, and ensure that the integral effect of the operation of all the layers is adequate for satisfying defense-in-depth.

5.3.3.2 Evaluation of the Oklo Reactor Licensing Basis Events Against the Layers of Defense

In this section, the Oklo reactor's LBEs are evaluated against the plant capability adequacy guidelines for the Layers of Defense. [redacted]

Table 5-13. [redacted]

[redacted]

}{(i)-(xi)}{eci}

The evaluation in this section proceeds by examining each layer of defense, the LBEs that impact that layer, and the plant design or operational features that impact the event sequence progression of each LBE affecting that layer. The defense-in-depth adequacy guidelines for each layer are then compared to the plant performance to make an adequacy determination.

5.3.3.3 Evaluation against Layer 1: Control of Disturbances and Transients

Layer 1 treats off-normal events of the most benign nature, even events that are too small to be classified as AOOs. Determining which events fall into this category is somewhat difficult, as the licensing basis event frequency-consequence category classification guidelines define AOOs as any LBE with a frequency greater than 1×10^{-2}/reactor-year. Regardless, the defense-in-depth adequacy of Layer 1 can be met by employing conservative design and operational approaches, and by using components with an appropriate level of quality assurance, as recommended by the IAEA Layers of Defense defense-in-depth guidance upon which the LMP guidance is based [28].

The many conservatisms taken in the design of the Oklo reactor are detailed throughout this report. As the design, fabrication, installation, and operation of the Oklo reactor's SSCs will follow the Oklo quality assurance program, they are assumed to possess an appropriate level of quality assurance. Accordingly, the plant capability defense-in-depth adequacy guidelines for Layer 1 are assessed to be met.

5.3.3.4 Evaluation against Layer 2: Control Abnormal Operation

Layer 2 treats events that fall in the Anticipated Occupational Occurrence (AOO) category of licensing basis events, with a frequency greater than 1×10^{-2}/reactor-year. [redacted]

[redacted]

5.3.3.4.1 [redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]

5.3.3.4.2 [redacted]

[redacted]

[redacted]

[redacted]

5.3.3.4.3 [redacted]

[redacted] {(i)-(xi)}{eci}

5.3.3.5 Evaluation Against Layer 3: Control Design Basis Events Within the Analyzed Design Basis Event Conditions

Layer 3 treats events that are classified into the Design Basis Events category of LBEs, with a event sequence frequency between 1×10^{-2}/reactor-year and 1×10^{-4}/reactor-year. [redacted]

[redacted]

5.3.3.5.1 [redacted]

[redacted]

5.3.3.5.2 [redacted]

[redacted]

5.3.3.5.3 [redacted]

[redacted]

[redacted]}(i)-(xi)}(eci)

5.3.3.6 Evaluation Against Layer 4: Control Severe Plant Conditions and Mitigate Consequences of Beyond Design Basis Events

Layer 4 treats events that are classified into the Beyond Design Basis Event category of LBEs, with an event sequence frequency of less than 1 × 10-4/reactor-year. [redacted]

[redacted]}(i)-(xi)}(eci)

5.3.3.7 Evaluation Against Layer 5: Mitigate radiological consequences of significant releases of radiological material

As detailed in the Design Basis Accident analysis and reiterated in the Layer 4 evaluation, due to its small size and associated small source term, the Oklo reactor is not capable of releasing large amounts of radioactive material. As such, the objective of Layer 5, which is to mitigate the radiological consequences of significant releases of radiological material, is met by default.

5.3.3.8 Evaluation Against the Overall Guidelines for Adequacy of Plant Capability Defense-in-Depth

The overall guidelines for adequacy of plant capability defense-in-depth are: 1) Meet the F-C target for all LBEs and cumulative risk metric targets with sufficient margins, and 2) Ensure that no single design or operational feature is exclusively relied upon to satisfy the five layers of defense. [redacted]

5.3.3.9 [redacted]

[redacted]

[redacted]}(i)-(xi)}{eci} and no barriers are assumed to be leak-tight – results in a dose an order of magnitude below the 50.34 requirements and two orders of magnitude below the QHOs[redacted]}. Thus, defense-in-depth goals, which are to ultimately protect the public from adverse health and safety impacts, is inherently satisfied by the Oklo reactor's small size, intrinsic safety, and small source term. Imposing burdensome additional component classifications, when those components have no bearing on public health and safety, is unnecessary to meet defense-in-depth.

5.3.3.10 Plant Capability Defense-in-Depth Attributes

This section of the LMP guidance lists generally-desirable attributes that the various plant features should collectively possess to help satisfy plant capability defense-in-depth adequacy. These attributes include initiating event and accident sequence completeness, layers of defense, functional reliability, and a balance between prevention and mitigation.

By employing bounding events for the simple, straightforward Oklo reactor design, the event and accident sequence analysis performed in Section 4 and Section 5 were found to satisfy the desired completeness characteristic. As discussed in Section 4 and Section 5.3.3, the Oklo design also employs multiple plant features to maintain its multiple layers of defense. The Oklo design's small size and simple design, with extensive passive systems and well-understood and demonstrated active systems, also satisfies functional reliability goals. By relying on a mixture of SSCs that perform prevention functions {[redacted]}(i)-(xi)}{eci} and systems that perform mitigation functions {[redacted]}(i)-(xi)}{eci}, the Oklo reactor employs both substantive prevention and mitigation of event sequences.

5.3.4 Establishing the Adequacy of Programmatic Defense-in-Depth

Programmatic defense-in-depth seeks to take a broader view of the plant design and safety analysis, to ensure that uncertainties are accounted for, oversights are identified and addressed, and that an appropriate amount of attention is paid to reducing risks wherever possible. Three attributes of programmatic defense-in-depth are specifically listed in the LMP guidance:

(1) Quality and reliability,

(2) Compensation for uncertainties, and

(3) Off-site response.

Oklo's quality assurance program is structured so as to produce a design with constituent parts that are reliable and of reliably high quality. Oklo's approach to uncertainty compensation is by assuming highly conservative values and conditions for performance and safety analysis, supplemented by uncertainty analyses where appropriate. Additionally, integrating a range of analytical outcomes with the risk analysis, as done in dynamic PRA analysis, captures a holistic event space which illustrates the potential effects of many different assumptions. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

5.3.5 Risk-Informed and Performance-Based Evaluation of Defense-in-Depth Adequacy

As a final step, a comprehensive re-review of the defense-in-depth adequacy of both plant capability and programmatic capability is recommended.

Four attributes are suggested to characterize this final stage of a single iteration's evaluation:

(1) Risk triplet examination,

(2) State of knowledge,

(3) Uncertainty management, and

(4) Action refinement.

The risk triplet is a set of three questions that seek to understand the potential failure modes and outcomes associated with the plant. The three questions are: 1) "What can go wrong?", 2) "How likely is it?", and 3) "What are the consequences?". These are essentially the same questions posed as part of the probabilistic risk assessment (Section 4) to construct the branching conditions of dynamic event trees, together with the dose analysis calculations informed by the PRA results (Section 4).

The state of knowledge catalogues the intended capabilities of the plant and constitutive systems, and matures into detailing the physical characteristics that implement these capabilities. Reviewing the design space explorations, sensitivity studies and associated configurations, the materials selections, and the resulting system performances in view of defense-in-depth objectives helps ensure that sensible opportunities for increasing defense-in-depth are embraced. Oklo's quality assurance program as implemented in the design process inherently enables in-process cataloguing of the design's current reference configuration as well as potential variants under exploration, together with their associated performance and safety envelope.

Understanding the sources and magnitudes of uncertainties helps to ensure that unexpected phenomena will not affect the general outcomes estimated by the design and safety analyses. Oklo's approach of recognizing uncertainties during the design process and accounting for them

with significantly conservative margins or sensitivity analyses helps manage these uncertainties during the design process.

Action refinement considers the practicality and potential effectiveness of implementing any measures to improve defense-in-depth. If, as part of the defense-in-depth adequacy review process, a need to improve defense-in-depth adequacy is recognized, the action refinement consideration is important to ensure that the cost and risk benefits of any suggested action are acceptable. Oklo applies these cost-benefit considerations for all design decision analyses, including those identified from defense-in-depth evaluations.

6 DESIGN OF FACILITY

6.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(4) has requirements for the design of the facility including:

> (i) The principal design criteria for the facility. Appendix A to part 50 of this chapter, "General Design Criteria for Nuclear Power Plants," establishes minimum requirements for the principal design criteria for water-cooled nuclear power plants similar in design and location to plants for which construction permits have previously been issued by the Commission and provides guidance to applicants in establishing principal design criteria for other types of nuclear power units;
>
> (ii) The design bases and the relation of the design bases to the principal design criteria;
>
> (iii) Information relative to materials of construction, arrangement, and dimensions, sufficient to provide reasonable assurance that the design will conform to the design bases with adequate margin for safety.

The purpose of this section is to provide an evaluation of the design criteria for the structures, systems, and components (SSCs) of the Oklo design.

6.1 Design Criteria Evaluation

The licensing basis event (LBE) selection process results in a classification of LBEs and a determination of safety functions of the Oklo design. Because the credible and risk-informed LBEs results in a zero dose, the risk (i.e., frequency multiplied by consequence) of the Oklo LBEs is also zero. Additionally, the deterministically selected design basis accident results in a dose well under the regulatory limit. Since all active SSCs are assumed to fail for this deterministic analysis, there are no identified safety functions. Passive SSCs are assumed to not retain their integrity; this is reflected through the analysis as these barriers are assumed to leak significantly (i.e., to not be leak tight).

Section 52.79(a)(4) to 10 CFR and the licensing modernization project require that principal design criteria (PDC) are established for the facility to ensure that SSCs that function to support safety-significant and risk-significant functions are available [25]. [redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

7 FIRE PROTECTION

Title 10 to the Code of Federal Regulations (CFR) Section 52.79(a)(6) requires, "A description and analysis of the fire protection design features for the reactor necessary to comply with 10 CFR part 50, appendix A, GDC 3, and § 50.48 of this chapter."

Oklo is not piloting this section.

Future work will include an evaluation of the Oklo design against 10 CFR Part 50.48, "Fire protection." Several design features of the Oklo reactor are conducive to inherently meeting the fire protection requirements, including:

- The reactor enclosures are filled with an inert gas, limiting potential for ignition,
- [redacted] {(i)-(xi)}
- Systems that may pose a fire threat are physically separated, and
- The site does not have a traditional switchyard, which is typically a comparatively high fire risk.

8 STATION BLACKOUT

Title 10 to the Code of Federal Regulations (10 CFR) Section 50.79(a)(9) requires coping analyses and relevant design features as they relate to a station blackout event. Further, 10 CFR 50.63, "Loss of all alternating current power," requires that each light water cooled nuclear power plant be able to withstand and recover from a station blackout (SBO). A station blackout is a complete loss of offsite alternating current (AC) power concurrent with a turbine trip and the unavailability of onsite emergency AC power system. This requires each plant to demonstrate sufficient capacity and capability to ensure that the reactor core is cooled and appropriate containment integrity is maintained in the event of an SBO for the specified duration. Passive plants are required to demonstrate that safety-related functions can be performed without reliance on AC power for 72 hours after the initiating event[22].

Oklo is not piloting this section.

For the purposes of this pilot, Oklo is analyzing only normal operation, and is not considering events following reactor shutdown. Therefore, the detailed analysis for an SBO is out-of-scope.

The Oklo design will be analyzed against 10 CFR 50.63. The relevant guidelines of Regulatory Guide (RG) 1.155, "Station blackout," will be used to inform this section as they pertain to compliance with 10 CFR 50.63 for the passive Oklo design, but it is important to note that full compliance with RG 1.155 is unnecessary for the Oklo design.

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

[22] The SBO duration for passive plant designs is 72 hours, which is consistent with NRC policy provided by SECY-94-084, "Policy and technical issues associated with the regulatory treatment of non-safety systems in passive plant designs," and SECY-95-132, "Policy and technical issues associated with the regulatory treatment of non-safety systems (RTNSS) in passive plant designs (SECY-94-084)." and the associated staff requirements memorandums.

9 ELECTRICAL EQUIPMENT IMPORTANT TO SAFETY

9.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(10) requires a description of the program, and its implementation, required by 10 CFR 50.49(a) for the environmental qualification of electric equipment important to safety and the list of electric equipment important to safety that is required by 10 CFR 50.49(d).

Paragraph b to 10 CFR 50.49 defines electric equipment important to safety covered by this section as follows:

(1) Safety-related electric equipment[23].

(i) This equipment is that relied upon to remain functional during and following design basis events to ensure—

(A) The integrity of the reactor coolant pressure boundary;

(B) The capability to shut down the reactor and maintain it in a safe shutdown condition; or

(C) The capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposures comparable to the guidelines in § 50.34(a)(1), § 50.67(b)(2), or § 100.11 of this chapter, as applicable.

(ii) Design basis events are defined as conditions of normal operation, including anticipated operational occurrences, design basis accidents, external events, and natural phenomena for which the plant must be designed to ensure functions (b)(1)(i)(A) through (C) of this section.

(2) Nonsafety-related electric equipment whose failure under postulated environmental conditions could prevent satisfactory accomplishment of safety functions specified in subparagraphs (b)(1)(i)(A) through (C) of paragraph (b)(1) of this section by the safety-related equipment.

(3) Certain post-accident monitoring equipment[24].

The purpose of this section is to provide an overview of the applicability of 10 CFR 50.49 to the Oklo design.

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[23] Safety-related electric equipment is referred to as "Class 1E" equipment in IEEE 323–1974. Copies of this standard may be obtained from the Institute of Electrical and Electronics Engineers, Inc., 345 East 47th Street, New York, NY 10017.

[24] Specific guidance concerning the types of variables to be monitored is provided in Revision 2 of Regulatory Guide 1.97, "Instrumentation for Light-Water-Cooled Nuclear Power Plants to Assess Plant and Environs Conditions During and Following an Accident." Copies of the Regulatory Guide may be purchased through the U.S. Government Publishing Office by calling 202–512–1800 or by writing to the U.S. Government Publishing Office, P.O. Box 37082, Washington, DC 20013–7082.

9.1 Evaluation

The safety classification process used for this preliminary analysis is different than the deterministic safety-related definition of 10 CFR 50.49(b)(1) and the nonsafety-related definition of 10 CFR 50.49(b)(2); this deterministic definition parallels the traditional definition of safety-related found in 10 CFR 50.2, "Definitions." [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

10 PROGRAMS RELATED TO ASME CODES

10.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(11) requires, "A description of the program(s), and their implementation, necessary to ensure that the systems and components meet the requirements of the ASME Boiler and Pressure Vessel Code and the ASME Code for Operation and Maintenance of Nuclear Power Plants in accordance with 50.55a of this chapter."

The purpose of this section is to provide an overview of Oklo's review of the requirements, and their subsequent applicability to the Oklo design, of the 10 CFR 52.79(a)(11) required American Society of Mechanical Engineers (ASME) codes. This section has been scoped to discuss the risk- and safety-significance of components as it applies to normal operations.

10.1 Evaluation

10.1.1 Introduction

Section 50.55a, "Codes and standards," to 10 CFR requires light water reactors (LWRs) to comply with certain codes and standards. Although the Oklo design is a non-LWR design, this section is analyzed for applicability regardless. Specifically, 10 CFR 50.55a(c), 10 CFR 50.55a(d), and 10 CFR 50.55a(e) state that certain systems and components of boiling- and pressurized-water-cooled nuclear power reactors must be designed, fabricated, erected, and tested in accordance with the standards for Class 1, 2, and 3 components given in Section III, "Nuclear Power Plant Components," of the ASME Boiler & Pressure Vessel Code (BPV Code), or equivalent quality standards, and the ASME Operation and Maintenance of Nuclear Power Plants (OM Code), Division 1, "Section IST: Rules for Inservice Testing of Light-Water Reactor Power Plants."

To appropriately review 10 CFR 50.55a for applicability to the Oklo design for this pilot, analysis of structures, systems, and components (SSCs) for their classification as it relates to the classification outlined in 10 CFR 50.55a must be performed and informed according to the LMP process for the DG-1353. This was informed by the regulation as well as the quality classification system outlined in Regulatory Guide (RG) 1.26, "Quality Group Classifications and Standards for Water-, Steam-, and Radioactive-Waste-Containing Components of Nuclear Power Plants[25]," which has been used as guidance by LWRs for satisfying quality requirements of General Design Criteria 1, "Quality standards and records," as set forth in Appendix A, "General design criteria for nuclear power plants," to 10 CFR Part 50. The quality classification system consists of four quality groups, A through D, including methods for assigning components to those quality groups and specific quality standards applied to each quality group. Each of the major portions of 50.55a are discussed below with a brief evaluation of the applicability to the Oklo design as appropriate within the scope of this pilot.

[25] Specifically, Revision 5 of RG 1.26 is used.

10.1.2 Quality Group Evaluation

10.1.2.1 Quality Group A, or 10 CFR 50.55a(c) components

10 CFR 50.55a(c) defines a group of SSCs having to do with the "Reactor coolant pressure boundary," as:

> Systems and components of boiling and pressurized water-cooled nuclear power reactors must meet the... Standards requirement for reactor coolant pressure boundary components.

In RG 1.26, this is defined as Quality Group A, which, while not explicitly defined in 10 CFR 50.55a(c), corresponds to the category of components presented in 10 CFR 50.55a(c)(1). As stated in 10 CFR 50.55a(c)(1), these components must meet the requirements for Class 1 components in Section III of the BPV Code.

This requirement is specified for boiling and pressurized water-cooled nuclear power plants, which does not apply for the Oklo reactor.

However, the intent of the regulation may be further analyzed. [redacted]} {(i)-(xi)}

10.1.2.2 Quality Group B

10 CFR 50.55a(d) states:

> (d) *Quality Group B components.* Systems and components of boiling and pressurized water-cooled nuclear power reactors must meet the requirements of the ASME BPV Code as specified in this paragraph.

RG 1.26 clarifies that Quality Group B corresponds to the category of components that include water and steam containing pressure vessels, heat exchangers, storage tanks, piping, pumps, and valves that are either (1) part of the reactor coolant pressure boundary, or (2) not part of the reactor coolant pressure boundary but part of several systems or portions of systems important to safety. For example, some traditional systems included in this quality group may include emergency core cooling, post-accident containment heat removal, post-accident fission product removal, reactor shutdown, residual heat removal, and other LWR specific systems.

The requirement of 50.55a(d) is specified for boiling and pressurized water-cooled nuclear power plants, which does not apply for the Oklo reactor.

However, the intent of the regulation may be further analyzed. [redacted]

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

10.1.2.3 Quality Group C

10 CFR 50.55a(e) states:

> (e) *Quality Group C components.* Systems and components of boiling and pressurized water-cooled nuclear power reactors must meet the requirements of the ASME BPV Code as specified in this paragraph.

RG 1.26 clarifies that Quality Group C corresponds to the category of components that include water, steam, and radioactive-waste containing pressure vessels; heat exchangers; storage tanks; piping; pumps; and valves that are not part of the reactor coolant pressure boundary but are part of several systems or portions of systems important to safety. For example, some traditional systems included in this quality group may include cooling water, auxiliary feedwater, and seal water systems as well as other LWR specific systems connected to the reactor coolant pressure boundary that are isolated by two valves.

The requirement of 50.55a(e) is specified for boiling and pressurized water-cooled nuclear power plants, which does not apply for the Oklo reactor.

However, the intent of the regulation may be further analyzed. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

To analyze intent to more depth, RG 1.26 states:

> The Quality Group C standards given in Table 1 on page 7 of this guide should be applied to water-, steam-, and radioactive-waste-containing pressure vessels; heat exchangers (other than turbines and condensers); storage tanks; piping; pumps; and valves that are not part of the reactor coolant pressure boundary or included in Quality Group B but part of the following:
>
> (a) cooling water and auxiliary feedwater systems or portions of those systems important to safety that are designed for (i) emergency core cooling, (ii) post-accident containment heat removal, (iii) post-accident containment atmosphere cleanup, or (iv) residual heat removal from the reactor and from the spent fuel storage pool (including primary and secondary cooling systems), although Quality Group B includes portions of those systems that are required for their safety functions and that (i) do not operate during any mode of normal reactor operation and (ii) cannot be tested adequately;

(b) cooling water and seal water systems or portions of those systems important to safety that are designed for the functioning of components and systems important to safety, such as reactor coolant pumps, diesels, and the control room;

(c) systems or portions of systems that are connected to the reactor coolant pressure boundary and are capable of being isolated from that boundary during all modes of normal reactor operation by two valves, each of which is either normally closed or capable of automatic closure[4]; and

(d) systems, other than radioactive waste management systems[5], not covered by Regulatory Positions 2(a) through 2(c) (above) that contain or may contain radioactive material and whose postulated failure would result in conservatively calculated potential offsite doses [using meteorology as recommended in RG 1.3, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss-of-Coolant Accident for Boiling-Water Reactors" (Ref. 12), and RG 1.4, "Assumptions Used for Evaluating the Potential Radiological Consequences of a Loss-of-Coolant Accident for Pressurized-Water Reactors" (Ref. 13)] that exceed 0.5 rem to the whole body or its equivalent to any part of the body; only single component failures need be assumed for those systems located in Seismic Category I structures, and no credit should be taken for automatic isolation from other components in the system or for treatment of released material, unless the isolation or treatment capability is designed to the appropriate seismic and quality group standards and can withstand loss of offsite power and a single failure of an active component.

Portions (a) and (b) pertain to items important to safety. [redacted] }{(ii)-(iv), (vi), (ix)-(xi)}

Portion (c) refers to SSCs related to the reactor coolant pressure boundary, which is not applicable to the Oklo design.

Portion (d) refers to guidance specific for boiling-water reactors (RG 1.3) and guidance for pressurized-water reactors (RG 1.4), both of which not being applicable to the Oklo design. However, demonstrably conservative dose analysis was performed for this pilot of DG-1353, taking into account the most conservative meteorological conditions possible, as described in Section 5. [redacted] }{(ii)-(iv), (vi), (ix)-(xi)}

Therefore, the Oklo design does not include any Quality Group C components.

10.1.2.4 Notes on Quality Group D

Quality Group D is not a category listed or directly implied by 10 CFR 50.55a. Quality Group D, as defined by RG 1.26, corresponds to the category of components that include "water- and steam-containing components that are not part of the reactor coolant pressure boundary or included in Quality Groups B or C, but are part of systems or portions of systems that contain or may contain radioactive material."

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

10.1.3 ASME OM Code

The ASME OM Code is incorporated into NRC requirements in 10 CFR 50.55a.

Specifically, 10 CFR 50.55a(b) states:

> (b) *Use and conditions on the use of standards.* Systems and components of boiling and pressurized water-cooled nuclear power reactors must meet the requirements of the ASME BPV Code and the ASME OM Code as specified in this paragraph (b).

This requirement is specified for boiling and pressurized water-cooled nuclear power plants, which does not apply for the Oklo reactor.

However, the intent of the regulation may be further analyzed. The ASME OM Code specifies that the following components are scoped:

- Pumps and valves that are required to perform a specific function in shutting down a reactor to the safe shutdown condition, in maintaining the safe shutdown condition, or in mitigating the consequences of an accident,
- Pressure relief devices that protect systems or portions of systems that perform those functions, and
- Dynamic restraints (snubbers) used in systems that perform those functions or to ensure the integrity of the reactor coolant pressure boundary.

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

11 REACTOR VESSEL MAINTENANCE PROGRAM

11.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 50.79(a)(13) requires, "A description of the reactor vessel material surveillance program required by Appendix H to 10 CFR Part 50 and its implementation." Appendix H, "Reactor vessel material surveillance program requirements," to 10 CFR Part 50, requires a reactor vessel surveillance program to be implemented if the total fluence on the reactor vessel exceeds 1.0×10^{17} n per cm^2 (energy greater than 1 MeV) in ferritic materials, securing an adequate safety margin for the structural integrity of the reactor pressure vessel.

The following considerations have been accounted for in the design and analyses of the preliminary reactor enclosure maintenance program:

- Fluence calculations are considered for normal full power operating modes,
- Area of consideration is the region adjacent to the reactor core of the reactor enclosure, and
- The fuel is the only source of radioactivity in the core.

The purpose of this section is to determine the applicability of this section to the Oklo design.

11.1 Reactor Vessel Maintenance Program Evaluation

11.1.1 Introduction

Traditionally, reactor design utilizes a reactor pressure vessel whose structural integrity is determined through fracture mechanic evaluations that include the measurements or estimates of the fracture toughness of the material resulting from exposure to neutron irradiation and the thermal environment. As the plant operates, neutrons escaping from the reactor core impact the vessel beltline materials causing embrittlement to those materials. The main factors affecting steel embrittlement include [30]:

1. Type of steel and its composition and microstructure,
2. Exposure temperature,
3. Neutron environment,
4. Stress state, and
5. Combined embrittlement effects.

<u>However, the Oklo reactor does not use a reactor pressure vessel.</u> [redacted]

11.1.2 [redacted]

[redacted]}{(i)-(xi)}{eci}

11.1.3 Reactor Enclosure Design Considerations

Although the reactor enclosures are not considered leak tight, certain design considerations are given to ensure their performance for investment protection reasons and are briefly described here.

11.1.3.1 Material Selection

[redacted]}{(i)-(xi)}{eci} The inherent material properties of the enclosures ensure full functionality and mitigation of the deleterious effects of embrittlement for the duration of the expected fuel cycle life.

11.1.3.2 Shielding to Limit Fluence

In addition to a robust material choice for the reactor enclosures, the integrity of the enclosures is further guaranteed because the total fluence seen over the operating lifetime of the core is held to similar limits to those required by 10 CFR Part 50, Appendix H.

11.1.3.3 No Pressurization

The heat transport system permits the Oklo reactor to operate with no pressurization [redacted]{(i)-(xi)}{eci}. The absence of pressurization and flow of coolant removes the potential hazard of a pressurized thermal shock event, which in a LWR may challenge the integrity of the reactor enclosures. {

11.1.4 [redacted]

[redacted]}{(i)-(xi)}{eci}

12 MAINTENANCE RULE

12.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(15) requires, "A description of the program, and its implementation, for monitoring the effectiveness of maintenance necessary to meet the requirements of § 50.65 of this chapter."

Further, scope is defined in paragraph b to 10 CFR 50.65, "Requirements for monitoring the effectiveness of maintenance at nuclear power plants," as follows:

> (b) The scope of the monitoring program specified in paragraph (a)(1) of this section shall include safety related and nonsafety related structures, systems, and components, as follows:
>
> (1) Safety-related structures, systems and components that are relied upon to remain functional during and following design basis events to ensure the integrity of the reactor coolant pressure boundary, the capability to shut down the reactor and maintain it in a safe shutdown condition, or the capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposure comparable to the guidelines in Sec. 50.34(a)(1), Sec. 50.67(b)(2), or Sec. 100.11 of this chapter, as applicable.
>
> (2) Nonsafety related structures, systems, or components:
>
> (i) That are relied upon to mitigate accidents or transients or are used in plant emergency operating procedures (EOPs); or
>
> (ii) Whose failure could prevent safety-related structures, systems, and components from fulfilling their safety-related function; or
>
> (iii) Whose failure could cause a reactor scram or actuation of a safety-related system.

The purpose of this section is to provide an initial overview of systems that may be scoped under the requirements of 10 CFR 50.65. It is likely that the majority of 10 CFR 50.65 will not apply to the Oklo design.

12.1 Evaluation

The scope of applicable structures, systems, and components (SSCs), as defined in 10 CFR 50.65(b), include safety-related and nonsafety-related SSCs. Paragraph 1 of 10 CFR 50.65(b) includes safety-related SSCs that are relied upon to remain functional during and after design basis events within the applicable scope. [redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Paragraph 2 of 10 CFR 50.65(b) includes nonsafety-related SSCs that meet three other criteria. The Oklo design may include nonsafety-related SSCs that meet one or more of these criteria.

For the first criteria under 10 CFR 50.65(b)(2), SSCs are included that are relied upon to mitigate accidents or transients or are used in plant EOPs. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

For the second criteria under 10 CFR 50.65(b)(2), SSCs are included whose failure could prevent safety-related SSCs from performing their safety function. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

For the third criteria under 10 CFR 50.65(b)(2), SSCs are included if their failure could cause a reactor trip or actuation of a safety-related system. Further analysis is needed to determine if Oklo will include SSCs whose failure could cause a reactor trip. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

13 EARTHQUAKE CRITERIA

Title 10 to the Code of Federal Regulations (CFR) Section 52.79(a)(19) requires, "Information necessary to demonstrate that the plant complies with the earthquake engineering criteria in 10 CFR part 50, appendix S."

Oklo is not piloting this section.

Future work will include an evaluation of the Oklo design against 10 CFR Part 50, Appendix S.

Seismic events have traditionally been considered the most bounding external events for metal-fueled fast reactors, primarily due to the possibility of large induced positive reactivity insertions caused by control rod motion relative to the core lattice. [redacted] {(i)-(xi)}{eci}

Seismic analysis of rigid bodies even partially below grade without substantive internal fluid inventories is a relatively trivial analysis even up to sizable seismic loadings. Initial research and analysis of the Oklo unit has shown that seismic events do not present such a challenge as they do for historical designs. However, this will be confirmed via additional analysis.

14 UNRESOLVED AND GENERIC SAFETY ISSUES

14.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(20) requires that an applicant proposes technical resolutions of those safety issues based on the most updated version of NUREG-0933, "Resolution of Generic Safety Issues," up to six months prior to the docket date of the application.

Oklo reviewed NUREG-0933 for applicability to nonlight water reactors and other reactors that may have technology crossover to the Oklo design.

14.1 Unresolved and Generic Safety Issues Evaluation

Oklo has determined that there are no unresolved or medium- and high-priority generic safety issues that are technically relevant to the design. As 10 CFR 52.79(a)(20) requires that an applicant proposes technical resolutions of those safety issues based on the most updated version of NUREG-0933 up to six months prior to the docket date of the application, Oklo will consider the most updated version of NUREG-0933 prior to submitting a final application.

As of August 2018, the vast majority of safety issues identified in NUREG-0933 are specific to light water reactors. Of the safety issues not specific to light water reactors, each is determined to not have relevance to the Oklo design:

- Task 1.IV.C: "Extend Lessons Learned to Licensed Activities Other than Power Reactors" describes experience with resin degradation; as the Oklo design does not have chemical cleanup or control, this is not relevant; and

- Task 5.CH6: "Graphite-Moderated Reactors" recommends studies that are specific to high temperature gas reactors.

Thus, it was determined that there are no unresolved or medium- and high-priority generic safety issues that are technically relevant to the Oklo design.

15 EMERGENCY PLANS

15.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(21) requires emergency plans that comply with the requirements of 10 CFR 50.47, "Emergency plans," and Appendix E, "Emergency planning and preparedness for production and utilization facilities," to 10 CFR Part 50.

Because Oklo's unique high power cost market demands a relatively small power source, the Oklo reactor has similar power level and quantities of nuclear material to a nonpower reactor. Although nonpower reactors vary in size, they are typically on the order of 10MWth or less[26], which is two orders of magnitude less than a commercial power reactor. The Oklo reactor will also operate at a thermal power of less than 10 MWth. Similarly, the amount of nuclear material in the Oklo reactor is at least an order of magnitude less than a commercial power reactor by total fuel weight. This substantial reduction in radioactive material is one key to the inherent safety of the Oklo design. Although the Oklo reactor produces power that will be sold commercially, and it will be licensed as a commercial reactor, the emergency plan is informed by nonpower reactor guidance for these reasons.

As such, Oklo has informed its emergency plan with ANSI/ANS 15.16-2015, "Emergency Planning for Research Reactors," which is endorsed by Regulatory Guide 2.6, "Emergency Planning for Research and Test Reactors and Other Non-power Production and Utilization Facilities," Revision 2.

15.1 Introduction

The Oklo reactor is a compact fast reactor that functions almost entirely with passive components. The reactor produces less than 10 MWth, which can be utilized to generate electricity, process heat, or cogeneration depending on the needs of the site.

The Oklo reactor is designed to be able to be placed in the majority of the U.S. This flexibility is in part enabled by the small size of the system. Although site descriptions are typically included in the emergency plan, by using conservative analyses, this emergency plan has been generalized for applicability across the U.S.

The objective of the Oklo emergency plan is to provide a basis for action, to identify personnel and material resources, and to designate areas of responsibility for coping with any emergency at an Oklo site. This emergency plan identifies both onsite and offsite support organizations that are required to be contacted for specialized assistance depending upon the nature of the emergency.

15.2 Definitions

The Oklo design does not use unique terms in this preliminary plan.

[26] Nonpower reactors vary in power level from 0.000005 MWth to 20 MWth. Roughly 40% of nonpower reactors are licensed at or below 10 MWth according to the NRC in the publicly available dataset, "Operating U.S. Nuclear Research and Test Reactors - Regulated by the NRC." This data set was last updated on July 1, 2016.

15.3 Organization and Responsibilities

Oklo is responsible for planning and implementing all emergency measures within the site boundary. [redacted] {(ii)-(iv), (vi), (ix)-(xi)} The relatively simple organizational structure outlined here is sufficient to adequately handle onsite emergencies and notification of unusual events.

At each site, Oklo plans to establish and maintain relationships with local emergency services, including law enforcement, medical, ambulance, and fire services. These local emergency services serve to supplement the emergency response.

15.3.1 Emergency Organization

[redacted]}(ii)-(iv), (vi), (ix)-(xi)} Following an emergency, the emergency organization conducts recovery actions.

15.3.2 Onsite Emergency Coordinator

[redacted].}(ii)-(iv), (vi), (ix)-(xi)} The onsite emergency coordinator (OEC) is the principal individual responsible for the security and safety of the Oklo site during an emergency. The OEC is responsible for obtaining and coordinating resources required for emergency operations. To fulfill these responsibilities, the OEC may summon assistance as necessary from local law enforcement, medical, ambulance, and fire services. The OEC has final authority over all onsite activities and personnel. The OEC is responsible for the following actions:

- Declaring an emergency based on observed action levels or events,
- Activating the emergency organization,
- Making radiological assessments,
- Making protective action decisions,
- Authorizing radiation exposures to emergency team members in excess of normal occupational limits,
- Declaring the termination of an emergency, and
- Initiating and overseeing recovery actions.

Although the OEC may rely on other personnel who may provide information, advice, counseling, or carry out instructions, the OEC cannot delegate OEC responsibilities. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

Offsite or community organizations may be requested by the OEC to assist the emergency organization. Assistance and support services that are provided by these community organizations include firefighting, emergency transportation, medical facilities, and additional police services. Written plans and procedures involving these community organizations are reviewed periodically by the OEC, along with the results of planned practice drills.

A central Oklo organization is likely to conduct actions such as annual reviews of emergency plans and subsequent updates, emergency training, and emergency tests and drills.

15.3.3 Onsite Emergency Supporter

The secondary site monitor serves as the onsite emergency supporter (OES), who is responsible for supporting the OEC in emergency response. The OES is responsible for the following actions:

- Supporting response from local emergency services, and
- Relating information about the emergency situation to the news media and the public.

15.3.4 Local Emergency Services

At each site, Oklo expects to establish and maintain arrangements and agreements with local emergency services to supplement the emergency response. These local emergency services include law enforcement, medical, ambulance, and fire services. Agreements with these agencies are confirmed in writing and updated periodically.

Local law enforcement may be summoned for security assistance, emergency radio communications, and traffic control as deemed necessary by the OEC.

A local medical facility is identified to provide care for individuals suffering a non-radiation related injury on the Oklo site. Contamination of individuals is unlikely even during emergency situations; therefore, decontamination is considered outside the scope of this pilot.

A local fire department may provide fire emergency services if deemed necessary by the OEC.

15.4 Emergency Classification System

The emergency classifications described for the Oklo site are based upon either credible accidents associated with the Oklo reactor operations or other emergency situations that are non-reactor related or have minimal radiological consequences. Each class has appropriate actions for the specific type of emergency situation.

15.4.1 Onsite Emergencies

Onsite emergencies are those events that could occur at the Oklo site that do not bear any risk to the public. These types of emergencies do not endanger the public and may require medical services. These types of events do not require notification of the NRC.

15.4.2 Notification of Unusual Events

Notification of unusual events may be initiated by either man-made events or natural phenomena that can be recognized as creating a significant hazard potential that was previously nonexistent. No releases of radioactive material requiring offsite responses are expected or credible.

One or more elements of the emergency organization are likely to be activated or notified to increase the state of readiness as warranted by the circumstances. Although the situation may not have caused damage to the reactor, it may warrant a shutdown of the reactor or interruption of nonessential routine functions.

Emergency measures associated with this class are initiated if the following action levels or events occur:

- [redacted]
    - [redacted]
    - [redacted] {(ii)-(iv), (vi), (ix)-(xi)}
- Report or observation of a severe natural phenomenon affecting the site.
- Receipt of a credible security threat affecting the site.
- Fire within the reactor that is not extinguished within 15 minutes. {

15.4.3 [redacted]

[redacted]

15.4.4 [redacted]

[redacted]

15.4.5 [redacted]

[redacted]

15.5 [redacted]

[redacted]

15.6 [redacted]

[redacted] }{(ii)-(iv), (vi), (ix)-(xi)}

15.7 Emergency Response

15.7.1 Activation of the Emergency Organization

[redacted] }{(ii)-(iv), (vi), (ix)-(xi)} The OEC is responsible for [redacted] }{(ii)-(iv), (vi), (ix)-(xi)} determining if other members of the emergency organization are needed.

15.7.2 Protective Action Values

Because of the inherent safety of the Oklo reactor, it is expected that all exposures of emergency personnel responding to a credible event will be well within the limits of 10 CFR Part 20, "Standards for Protection against Radiation," and the PAGs of 1 rem whole body or 5 rem thyroid. [redacted] }{(ii)-(iv), (vi), (ix)-(xi)}

15.7.3 Report of an Emergency

The emergency notification roster is posted in multiple locations at each site [redacted] }{(ii)-(iv), (vi), (ix)-(xi)}. The emergency notification roster contains information regarding whom should be contacted and what detailed information should be provided in case of an emergency.

15.7.4 Emergency Response for Onsite Emergency

15.7.4.1 Activation of Emergency Organization for Onsite Emergency

[redacted] }{(ii)-(iv),

---

27 [redacted]

(vi), (ix)-(xi)} It is usually not necessary for the OEC to completely activate the emergency organization for this classification. The OEC activates only that portion of the emergency organization required to respond to the scope of an emergency or event.

15.7.4.2 Assessment Actions for Onsite Emergency

Injured Person

In the case of an injured person, the OEC is responsible for assessing the extent of the injury and determining whether radioactive contamination is present. Portable radiation monitoring devices are readily available throughout the site. In the assessment, the OEC takes into consideration the nature of the injury, appropriate first aid measures required or implemented, and the need for transport to medical treatment facilities.

Fire or Explosion

The OEC is responsible for assessing a fire or explosion event to determine the magnitude of the event, need for prompt control, and need for auxiliary support from offsite services.

15.7.4.3 Corrective Actions for Onsite Emergency

Injured Person

The OEC is responsible for determining what medical assistance is needed for an injured person with or without radiological complications and may contact local ambulance services for transportation to a medical facility.

Fire or Explosion

For minor fires or explosions, onsite personnel may attempt to control the fire with portable fire extinguishers if it does not present excessive risk. In the event that a fire is not extinguished, the OEC is responsible to ensure the local fire department is notified immediately.

15.7.4.4 Protective Actions for Onsite Emergency

Some protective actions may require evacuation. Evacuations may be initiated by activating the fire alarm and/or verbally notifying all personnel. Primary and alternate assembly areas following evacuation will be determined for each site. [redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

15.7.5 Emergency Response for Notification of Unusual Event

15.7.5.1 Activation of Emergency Organization for Notification of Unusual Event

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)} The OEC activates only that portion of the emergency organization required to respond to the scope of an emergency or event.

15.7.5.2 Assessment Actions for Notification of Unusual Event

Radiation Release

The OEC is responsible to assess the status of systems in the reactor if unusual radiation levels are detected. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

Security Threat

Upon receipt of a credible security threat, the OEC is responsible for contacting local law enforcement.

Fire or Explosion

The OEC is responsible for assessing a fire or explosion event to determine the magnitude of the event and need for auxiliary support from offsite services.

Natural Phenomenon

Upon knowledge of a severe natural phenomenon affecting the site, the OEC is responsible to monitor the status of the phenomenon and its potential impact and timeline for affecting the site.

15.7.5.3 Corrective Actions for Notification of Unusual Event

Radiation Release

Following an assessment of the cause of high radiation levels, the OEC may initiate a reactor trip. The OEC may also restrict access until radiation and airborne activity levels have been restored to normal.

Security Threat

The OEC is responsible to continue coordinating the response of the emergency organization but generally defers security decisions to local law enforcement.

Fire or Explosion

[redacted] {(ii)-(iv), (vi), (ix)-(xi)} In the event that a fire is not extinguished with basic measures, the local fire department is notified immediately. As able, the OEC may monitor the extent of the fire and brief firefighters upon their arrival.

Natural Phenomenon

Following an assessment of the natural phenomenon, the OEC may initiate appropriate site actions or evacuation of the site building, or both. {

15.7.5.4 [redacted]

[redacted]

15.7.6 [redacted]

[redacted]

15.7.7 [redacted]

[redacted]

15.7.8 [redacted]

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

15.8 Emergency Facilities and Equipment

15.8.1 Emergency Support Center

An emergency support center serves as a central point for emergency actions. [redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

15.8.2 Assessment Facilities

Radiation detectors are located throughout the site, including [redacted]}{(ii)-(iv), (vi), (ix)-(xi)} at the site boundary. Earthquake sensors and fire and combustion product detectors are also located throughout the site. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

15.8.3 First Aid and Medical Facilities

The OEC is responsible to determine the appropriate assistance for injured persons and may administer first aid when appropriate. The OEC also summons an ambulance for transport of the patient to a local medical facility if needed.

15.8.4 Communications Equipment

Telephones and radios may be one method of communication during an emergency. [redacted] (ii)-(iv), (vi), (ix)-(xi)} All telephones may be utilized during emergencies. Direct verbal communications are also used to back up telephone

and radio communications. Additional backup means of communication will be identified depending on the specific site for compatibility with local offsite support organizations.

15.8.5 Contingency Planning

Contingency plans for each site will be developed as needed.

15.9 Recovery

Information related to recovery is outside the scope of this pilot.

15.10 Maintaining Emergency Preparedness

15.10.1 Training and Drills

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)} Specific training in protective action decision-making is included in the initial and subsequent refresher training. As the OEC may provide first aid to injured persons, this training program ensures that the OEC is appropriately trained in first aid and CPR. Offsite support groups will receive training commensurate with their potential degree of involvement.

Onsite emergency drills, overseen by the OEC, are conducted annually to test the adequacy of emergency procedures. These drills include the use of appropriate emergency equipment and a test of the communications links with the remote monitoring center and offsite emergency organizations.

At the conclusion of each drill, participating personnel critique the drill to identify any deficiencies and to suggest improvements to ensure reliable response in an emergency or unusual event. The OEC is expected to evaluate comments and consider possible changes in the emergency plan and procedures.

15.10.2 Plan Review and Update

The emergency plan is periodically reviewed and updated by a central Oklo organization to ensure that the plan is adequate and current. The review process considers the results and feedbacks of emergency drills. Additionally, written agreements that detail arrangements with local emergency services are reviewed to ensure continuity of emergency service.

15.10.3 Equipment Maintenance

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)} Equipment maintenance includes required maintenance and calibrations, testing, and periodic inventory.

16 EMERGENCY PLANNING WITH STATE AND LOCAL GOVERNMENTS

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(22) requires that:

> (i) All emergency plan certifications that have been obtained from the State and local governmental agencies with emergency planning responsibilities must state that:
>
> > (A) The proposed emergency plans are practicable;
> >
> > (B) These agencies are committed to participating in any further development of the plans, including any required field demonstrations; and
> >
> > (C) These agencies are committed to executing their responsibilities under the plans in the event of an emergency;
>
> (ii) If certifications cannot be obtained after sustained, good faith efforts by the applicant, then the application must contain information, including a utility plan, sufficient to show that the proposed plans provide reasonable assurance that adequate protective measures can and will be taken in the event of a radiological emergency at the site.

Oklo is not piloting this section.

Because the Oklo reactor can be placed throughout the majority of the U.S., associated emergency plans, as described in Section 15, have been generalized for applicability across the U.S. and are not specific to any one state or locality.

Oklo is aware of the importance of developing and maintaining strong relationships with state and local governmental agencies, including law enforcement, medical, ambulance, and fire services. As site-specific considerations are included in emergency plans for particular sites, input from state and local governmental agencies will be considered. This input includes recommendations and changes to emergency procedures as well as the development of training and onsite drill procedures. As the emergency plans are finalized, the appropriate certifications will be obtained as required by 10 CFR 52.79(a)(22).

17 PROTOTYPE OPERATIONAL CONDITIONS

17.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 50.43(e), which applies to applications for designs that differ significantly from pre-1997 light water reactor designs or use passive safety means to accomplish safety functions, requires that applicants demonstrate their safety features through either prototype testing or sufficient analysis, testing and experimentation.

The purpose of this section is to evaluate the applicability of 10 CFR 50.43(e) to the Oklo design.

17.1 Evaluation

Oklo does not intend to construct a prototype reactor, and will instead show through sufficient analysis, testing and experimentation that the reactor will perform as required.

Oklo's licensing basis events selection process, described in Section 5, was used to identify any safety functions required by the structures, systems, and components of the Oklo reactor. This process was informed by Oklo's probabilistic risk assessment and evaluated against the frequency-consequence targets provided by the Licensing Modernization Project and endorsed in the DG-1353. [redacted] {(ii)-(iv), (vi), (ix)-(xi)} Therefore, the requirements of 10 CFR 50.43(e) are met by default.

While Oklo is not constructing a prototype reactor, much of the basis of the analysis is from operational experience data for key reactor components and materials. In particular, metal fuel has extensive operating history that demonstrates its favorable properties, including inherent negative feedbacks, that are a major factor in the safety analysis [3].

18 DESIGN AND CONSTRUCTION QUALITY ASSURANCE PROGRAM DESCRIPTION

Title 10 to the Code of Federal Regulations Section 52.79(a)(25) requires a description of the quality assurance program applied to the design, and to be applied to the fabrication, construction, and testing, of the structures, systems, and components of the facility.

Oklo is not piloting this section.

The Oklo quality assurance program description will be submitted as a topical report.

19 ORGANIZATION STRUCTURE FOR OPERATIONS

19.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(26) requires that the applicant's organizational structure, allocations or responsibilities and authorities, and personnel qualifications requirements for operation be provided.

The focus of the organizational structure described in this section is on the operations of specific sites; that is, the roles responsible for maintenance, procurement, testing, and engineering are outside of the scope of this section.

19.1 Evaluation

This section describes the organizational positions of Oklo plant operations and the associated functions and responsibilities. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

The first priority throughout the life of a unit is improving the lives of the community. Safety is a core aspect of this goal. Decision-making for onsite activities is performed in a conservative manner with expectations of this core value. Lines of authority, decision making, and communication are clearly and unambiguously established to promote effective operations.

[redacted]

19.1.1 [redacted]

[redacted]

[redacted]

[redacted]

19.1.2 [redacted]

[redacted]

19.1.3 [redacted]

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

20 OPERATIONAL ELEMENTS OF THE QUALITY ASSURANCE PROGRAM DESCRIPTION

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(27) requires managerial and administrative controls to be used to assure safe operation as required by portions of Appendix B, "Quality assurance criteria for nuclear power plants and fuel reprocessing plants," to 10 CFR Part 50.

Oklo is not piloting this section.

21 PREOPERATIONAL TESTING AND INITIAL OPERATIONS

Title 10 to the Code of Federal Regulations Section 52.79(a)(28) requires that plans for preoperational testing and initial operations be provided.

Oklo is not piloting this section.

For the purposes of this pilot, Oklo is analyzing only normal operation, and is not considering preoperational and startup modes. Typically, the initial test program (ITP) consists of tests that are performed, evaluated and completed prior to the plant entering the normal operating mode. As such, the ITP is outside of the scope of this pilot. Similarly, Inspections, Tests, Analyses, and Acceptance Criteria (ITAAC) are typically developed for implementation prior to fuel load, so complete development of all of the anticipated ITAAC is also outside of the scope of this pilot.

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

22 OPERATIONAL PLANS

22.0 Purpose and Scope

Title 10 to the Code of Federal Regulations Section 52.79(a)(29) requires that applicants provide:

> (i) Plans for conduct of normal operations, including maintenance, surveillance, and periodic testing of structures, systems, and components;
>
> (ii) Plans for coping with emergencies, other than the plans required by § 52.79(a)(21);

Regulatory Guide (RG) 1.206, "Combined License Applications for Nuclear Power Plants," Section C.I.13.4 is used to inform the selection of operational programs required by the regulations. However, not every program in RG 1.206 will be applicable to the Oklo design.

The purpose of this section is to provide an overview of the applicability of operational programs to the Oklo design and serve as a summary of the locations of the programs in this pilot submittal.

22.1 Evaluation

22.1.1 Applicable Programs

This section lists the operational programs that will likely be applicable to the Oklo design and references their corresponding section in this pilot if they have been evaluated.

- Fire protection program (not piloted),
- Radiation protection program (Section 31),
- Plant staff training programs (Section 26),
- Emergency planning programs (Section 15),
- Security program (Section 28),
- Quality assurance program (Sections 18 and 20), and
- Initial test program (not piloted). {

22.1.2 [redacted]

[redacted]

- [redacted]
- [redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]
- [redacted]

22.1.3 [redacted]

[redacted]

- [redacted]
- [redacted]

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

23 TECHNICAL SPECIFICATIONS

Title 10 to the Code of Federal Regulations Section 52.79(a)(30) requires, "Proposed technical specifications prepared in accordance with the requirements of §§ 50.36 and 50.36a of this chapter."

Oklo is not piloting this section.

24 TECHNICAL QUALIFICATIONS OF THE APPLICANT

24.0 Purpose and Scope

Title 10 to the Code of Federal Regulations Section 52.79(a)(32) requires that the technical qualifications of the applicant be provided.

[redacted] {(iii), (vi), (ix)-(xi)}

24.1 Evaluation

Oklo is a privately funded nuclear technology developer. Oklo was founded in 2013 [redacted]}{(iii), (vi), (ix)-(xi)}.

As Oklo is a relatively new company, its qualifications can most readily be explained by its sources of funding, testimonies, industry leadership roles, and awards. Oklo is funded by private investors with multiple rounds of due diligence [redacted]}{(iii), (vi), (ix)-(xi)}.

Oklo's CEO, Jacob DeWitte, has testified before the House of Representatives' Committee on Science, Space, and Technology (2017), the Senate's Committee on Energy and Natural Resources (2016), and serves as the Chair of the Fast Reactor Working Group, the largest and most diverse advanced reactor technology group, and on the Nuclear Energy Institute Board of Directors. Oklo's COO, Caroline Cochran, serves on the Department of Energy's Nuclear Energy Advisory Committee.

Oklo has won several awards, including the following: the top MIT team at the MIT Clean Energy Prize (2013), the winner of the energy track at the MIT 100k (2013), finalist at MassChallenge (2013), winner of the MassChallenge Gold Award (2013), and acceptance into the selective accelerator YCombinator (2014).

Oklo has also been awarded multiple vouchers through the Gateway for Accelerated Innovation in Nuclear (GAIN) program, providing access to technical expertise at Department of Energy laboratories including Argonne National Laboratory, Idaho National Laboratory, and Sandia National Laboratory. These awards demonstrate a recognition of Oklo's qualifications and serve as a means of leveraging the technical qualifications of the laboratory system to improve the Oklo design.

25 OPERATOR TRAINING PROGRAM

25.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(14) requires that a description of the operator training program, and its implementation, necessary to meet the requirements of 10 CFR Part 55, "Operators' licenses," be provided.

The purpose of this section is to provide an initial description of how operators at the Oklo site are treated. [redacted]}{(iii), (vi), (ix)-(xi)}

25.1 Evaluation

An operator is defined in 10 CFR 55.4, "Definitions," as "any individual licensed under this part to manipulate a control of a facility." Controls are defined as an "apparatus and mechanisms the manipulation of which directly affects the reactivity or power level of the reactor."

[redacted]

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

26 TRAINING PROGRAM

26.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(33) requires that a description of the training program required by 10 CFR 50.120, "Training and qualification of nuclear plant personnel," and its implementation be provided.

[redacted]

[redacted]

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

For the purposes of this pilot, Oklo is analyzing only normal operation and is not considering other operational modes such as startup or maintenance. Therefore, the scope of the training program described in this section is limited to normal operations.

26.1 Evaluation

26.1.1 Definitions

The following definitions are used to describe the training program:

academic training: academic training is successfully completed job-related college-level work.

certification: the confirmation by Oklo of the experience, education, medical condition, training, and testing pertinent to a specific job assignment.

certified: an individual holding a certification.

nuclear experience: experience acquired in reactor facility start-up activities or operation. Experience in design, construction, maintenance, or related technical services that are job-related may also be considered. On-the-job training at the reactor facility may qualify as equivalent nuclear experience on a one-for-one-time basis. Appropriate research or teaching or both may be includable as nuclear experience.

on-the-job training: a systematic, structured method using a qualified person to provide the required job-related knowledge and skills to a trainee, usually in the actual workplace, with proficiency documented.

26.1.2 Roles

The organizational structure of operations of a plant is described in Section 19. [redacted]

[redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted] }{(ii)-(iv), (vi), (ix)-(xi)}

26.1.3 Training Program Overview

The training program described in this section includes the following:

- Qualification, which ensures that personnel have the appropriate background to qualify for training;
- Initial training and certification, which ensures that personnel have both general and specific training to perform the required duties;
- Retraining, which ensures that personnel have received training within an appropriate timeframe; and
- Medical evaluation, which ensures that personnel have adequate physical and mental health to perform the required duties.

The training program described in this section will be reviewed and updated periodically by Oklo to ensure its continuing effectiveness, including the incorporation of industry experience as well as changes to facilities, procedures, regulations, and quality assurance requirements.

26.1.4 Qualification

Monitoring personnel are expected to have a combination of academic training, job-related experience, health, and skills to be considered qualified for training. [redacted]

26.1.4.1 [redacted]

[redacted]

26.1.4.2 [redacted]

[redacted]

26.1.4.3 [redacted]

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

26.1.5 Initial Training and Certification

All monitoring personnel are required to receive comprehensive training based on the knowledge and skill required to perform their functions safely and effectively. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

Both general and specific training are provided in a combination of classroom, on-the-job or simulator training, and self-study. General training includes nuclear and reactor technology, general operating characteristics, and radiation protection principles. Specific training applies to the individual site and includes reactor design and operation, instrumentation and controls, procedures and technical specifications, emergency preparedness, and applicable rules and requirements.

It is expected that Oklo will administer a combination of written, operating, and oral examinations with a minimum acceptance criteria to receive certification. Written examinations may include questions related to the following:

- Theory, including nuclear theory, principles of reactor operations, general and specific site characteristics, and applicable thermodynamics;

- Procedures and radiological controls, including normal procedures, off-normal procedures, emergency procedures, radiation protection principles and procedures, administrative rules, and technical specifications; and

- Systems, including unit systems, radiation protection systems, instrumentation and control, and engineered performance systems.

Operating and oral examinations are designed to evaluate an individual's knowledge and skill to properly act under normal and abnormal circumstances. These skills may include anticipation and response to events, site awareness, use of references, and communications. {

26.1.5.1 [redacted]

[redacted]

- [redacted]
- [redacted]
- [redacted]
- [redacted]

26.1.5.2 [redacted]

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

26.1.6 Retraining

It is expected that monitoring personnel will be subject to a periodic retraining program. The goals of this program are to refresh areas of infrequent action, to review site and procedural changes, to address subject matter not reinforced by direct use, and to improve in areas of performance weakness. The program will be designed to evaluate an individual's knowledge and proficiency to perform his or her duties and retrain where necessary, with an emphasis on the subjects necessary for continued proficiency. Following the retraining program, Oklo may administer an examination prior to issuing a renewed certification.

26.1.7 Medical Evaluation of Personnel

The physical condition and general health of monitoring personnel are evaluated to ensure that they are capable of properly carrying out certified activities under normal, abnormal, and emergency conditions. The following may be considered:

- Mental alertness and emotional stability;

- Acuity of senses and ability of expression to allow accurate communications by spoken, written, or other audible, visible, or tactile signals; and
- Stamina, motor power, range of motion, and dexterity as needed to allow ready access to and safe execution of certain assigned duties for the specific site.

26.1.8 Fitness for Duty

The fitness-for-duty program is not piloted.

26.1.9 Documentation and Records

The eligibility of certified personnel is appropriately documented, including the following:

- Education, experience, employment history, and medical evaluation,
- Training programs completed,
- Copy of the currently valid certification, and
- Records of retraining program.

[redacted] {(ii)-(iv), (vi), (ix)-(xi)}

27 OPERATOR REQUALIFICATION

27.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(34) requires that a description and plans for implementation of an operator requalification program be provided, which must, at a minimum, meet the requirements of 10 CFR 55.59 "Requalification." {

27.1 [redacted]

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

28 PHYSICAL SECURITY

28.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(35) requires the following:

> (i) A physical security plan, describing how the applicant will meet the requirements of 10 CFR part 73 (and 10 CFR part 11, if applicable, including the identification and description of jobs as required by § 11.11(a) of this chapter, at the proposed facility). The plan must list tests, inspections, audits, and other means to be used to demonstrate compliance with the requirements of 10 CFR parts 11 and 73, if applicable;
>
> (ii) A description of the implementation of the physical security plan;

For the purposes of this pilot document, a description of the general physical security approach is provided. It is expected that more detailed description of the implementation of the approach may be considered safeguards information and will not be submitted until after the appropriate procedures are in place.

The focus of this section is on normal operations. Therefore, requirements related to the security of transportation of nuclear material are not described.

28.1 Physical Security Overview

While the Oklo reactor is designed to produce power, its thermal power and amount of nuclear material are more similar to nonpower reactors than large light water reactors (LWR). [redacted] }{(ii)-(iv), (vi), (ix)-(xi)}

Because minimal guidance exists for commercial power reactors with thermal power levels on the order of 10 MWth or less, the physical security approach developed by Oklo and described in this document is a hybrid of physical protection plans for nuclear power reactors, nonpower reactors, and special nuclear material of moderate strategic significance. The physical protection plan requirements for these categories are listed below:

- Nuclear power reactors are required to meet 10 CFR 73.55, "Requirements for physical protection of licensed activities in nuclear power reactors against radiological sabotage."
- Nonpower reactors are required to meet 10 CFR 73.60, "Additional requirements for physical protection at nonpower reactors."
- Physical protection of special nuclear material of moderate strategic significance is required to meet 10 CFR 73.67, "Licensee fixed site and in-transit requirements of special nuclear material of moderate and low strategic significance."

Oklo expects its special nuclear material to be secured during normal operations because of the following security considerations:

- The inherent security advantages of the design described in Section 28.1.1.

- Theft of fuel during normal operations is not considered feasible and is described in Section 28.1.2.
- The physical security approach, described in Section 28.2, is guided by Regulatory Guide 5.59, "Standard Format and Content for a Licensee Physical Security Plan for the Protection of Special Nuclear Material of Moderate or Low Strategic Significance," to meet the requirements of 10 CFR 73.67.
- Supplemental, stricter requirements of Section 73.55 may be applied for future security plan submittals.

28.1.1 Security Advantages

The Oklo reactor poses a smaller security risk than typical LWRs for several reasons. The list below summarizes the security advantages:

- Much less fuel than a typical LWR,
- Fast spectrum fuel that is self-protecting,
- No fresh or spent fuel stored on site outside of the reactor,
- Difficulty of access to fuel, and
- Reactor located below grade.

First, the Oklo reactor contains at least an order of magnitude less fuel than a typical LWR. Less fuel makes Oklo reactors a less appealing target.

Second, the Oklo reactor operates in the fast spectrum without the use of a moderator. Without the shielding provided by a moderator, the fuel in the Oklo reactor is self-protecting and significantly more difficult to access. A hostile adversary attempting to steal fuel during normal operation would need large amounts of heavy shielding material, which is impractical.

Third, fresh or spent fuel is not stored onsite since the reactor is not refueled during the fuel cycle life. Thus, there are no spent fuel pools or dry cask storage containers which could be targeted by an adversary.

Fourth, fuel is difficult to access and could not be removed from the reactor quickly. In order to access the fuel, an adversary would need to move several physical barriers using heavy machinery. This process requires specialized equipment and would take a significant amount of time.

Fifth, the reactor is located below grade, which reduces potential actions that could be taken by hostile adversaries.

28.1.2 Security of Fuel

According to 10 CFR 73.60, nonpower reactor licensees are required to protect special nuclear material from theft or diversion as required by 10 CFR 73.60 and 73.67(a) through (d), unless it

can be shown that the special nuclear material possessed or used meets the following conditions:

- Is not readily separable from other radioactive material, and
- Has a total external radiation dose rate in excess of 100 rem/hour at a distance of 3 feet from any accessible surface without intervening shielding.

By showing these two conditions, nonpower reactor licensees are exempt from the requirements of 10 CFR 73.60(a) through (e). Similarly, 10 CFR 73.67(b)(1) states that a licensee is exempt from the requirements of 10 CFR 73.67 to the extent that it possesses, uses, or transports special nuclear material which meets the two conditions outlined in 10 CFR 73.60.

Shortly after startup, the fuel dose rate will meet the requirements for self-protection set out in the first condition, i.e., will be greater than 100 rem/hour at 3 feet without shielding. Additionally, the fuel meets the second condition as it is not separable without an advanced pyroprocessing plant. Because of this and the security advantages described in Section 28.1.1, the theft of fuel contained in the reactor during normal operations is not considered feasible.

28.2 Physical Security Approach

28.2.1 Use and Storage Area at Fixed Site

The use and storage of special nuclear material on the Oklo site is described in the following sections.

28.2.1.1 Area Where Material is Used

Paragraph 73.67(d)(1) to 10 CFR requires that special nuclear material only be used within a controlled access area which is illuminated sufficiently to allow detection and surveillance of unauthorized penetration or activities.

[redacted]

[redacted]

[redacted] {(i)-(xi)}

28.2.1.2 Area Where Material is Stored

Paragraph 73.67(d)(2) to 10 CFR requires that special nuclear material only be stored within a controlled access area such as a vault-type room or approved security cabinet or their equivalent which is illuminated sufficiently to allow detection and surveillance of unauthorized penetration or activities.

Because special nuclear material is not stored onsite, this requirement is met by default.

28.2.2 Detection Devices and Procedures at a Fixed Site

The devices and procedures used for detection of unauthorized access to controlled access a[redacted]s are described in the following sections.

28.2.2.1 Earliness of Detection

Paragraph 73.67(a)(2) to 10 CFR requires that the physical protection system provide early detection and assessment of unauthorized access or activities by an external adversary within the controlled access area and early detection of removal of special nuclear material by an external adversary from a controlled access area.

The early detection of unauthorized access by an adversary within the controlled access areas may be provided by a combination of the following:

- Onsite monitors,
- Tamper-indicating, alerting physical barriers,
- Interior video cameras,
- Exterior pan, tilt, zoom cameras, and
- Exterior thermal cameras.

28.2.2.2 Detection Through Monitoring Controlled Access Areas

Further, paragraph 73.67(d)(3) to 10 CFR requires that the controlled access areas be monitored with an intrusion alarm or other device or procedures to detect unauthorized penetration or activities.

[redacted] {(i)-(xi)}

28.2.3 Access Control at a Fixed Site

Access to controlled access areas is described in the following sections.

28.2.3.1 Preauthorization Screening

Paragraph 73.67(d)(4) to 10 CFR requires that a screening be conducted prior to granting an individual unescorted access to the controlled access areas where special nuclear material is used or stored.

[redacted]

- [redacted]
- [redacted]
- [redacted]

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

28.2.3.2 Badging System

Paragraph 73.67(d)(5) to 10 CFR requires that a controlled badging and lock system be developed and maintained to identify and limit access to the controlled access areas to authorized individuals.

Oklo expects to use a badging system to ensure that unauthorized individuals cannot access controlled access areas. The specifics of the badging system are considered safeguards information and are therefore not described here.

28.2.3.3 Lock System

Similarly, Oklo expects to use a locking system to ensure that unauthorized individuals cannot access controlled access areas. The specifics of the locking system are considered safeguards information and are therefore not described here.

28.2.3.4 Personnel Entry Control System

Paragraph 73.67(d)(6) to 10 CFR requires that access to the controlled access areas be limited to authorized or escorted individuals who require such access in order to perform their duties.

As described in Section 28.2.1, access to controlled access areas is restricted by access-controlled doors to authorized or escorted individuals.

28.2.3.5 Escort System

Paragraph 73.67(d)(7) to 10 CFR requires that all visitors to the controlled access areas are under the constant escort of an individual who has been authorized access to the area.

Oklo does not expect visitors to require access to the controlled access areas during normal operation. However, any visitors will be escorted by an authorized individual to access controlled access areas.

28.2.3.6 Search

Paragraph 73.67(d)(10) to 10 CFR requires vehicles and packages leaving the controlled access areas be searched on a random basis.

[redacted] {(i)-(xi)}

28.2.4 Security Organization at a Fixed Site

Paragraph 73.67(d)(8) to 10 CFR requires that a security organization be established to consist of at least one watchman per shift able to assess and respond to any unauthorized penetrations or activities in the controlled access areas.

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)} As described in Section 15, in the case of a security threat to the site, the onsite emergency coordinator is responsible for contacting local law enforcement. It is expected that the onsite emergency coordinator will defer decisions on actions to take during security threats to local law enforcement.

28.2.5 Communications at a Fixed Site

Paragraph 73.67(d)(9) to 10 CFR requires that a communication capability between the security organization and appropriate response force must be provided.

[redacted]

[redacted]}{(i)-(xi)}

28.2.6 Response Procedures at a Fixed Site

Paragraph 73.67(d)(11) to 10 CFR requires that response procedures for dealing with threats of thefts or actual thefts of these materials be established and maintained, and a copy of the response procedures be retained.

As described in Section 28.1.2, the theft of fuel during normal operations is not considered a feasible threat. Nonetheless, Oklo will likely develop response procedures for dealing with threats of thefts or actual thefts of special nuclear material during other modes of operation. These response procedures may be considered safeguards information and are therefore not described here.

28.2.7 Material Transportation Requirements

As the scope of the pilot and the physical security approach outlined in this section is on normal operations, transportation of special nuclear material is not described.

28.2.8 Receiver Requirements – Transportation

As the scope of the pilot and the physical security approach outlined in this section is on normal operations, transportation of special nuclear material is not described.

28.2.9 In-Transit Physical Protection Requirements

As the scope of the pilot and the physical security approach outlined in this section is on normal operations, transportation of special nuclear material is not described.

29 SAFEGUARDS

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(36) requires that the applicant provide a safeguards contingency plan and subsequent training and qualification plan.

Oklo is not piloting this section.

[redacted] {(iii), (iv), (ix)-(xi)}

30 INCORPORATION OF OPERATIONAL INSIGHTS

30.0 Purpose and Scope

Title 10 to the Code of Federal Regulations Section 52.79(a)(37) requires that the information necessary to demonstrate how operating experience insights have been incorporated into the plant design be provided.

The purpose of this section is to outline the steps taken to comply with 10 CFR 52.79(a)(37).

30.1 Evaluation

Throughout its design process, Oklo has considered the operating experience of past reactors and incorporated the successful aspects of those reactors. Consideration of operating experience insights includes searching over multiple reactor designs, including:

- Generic operating experience that affects all nuclear reactors,
- Metal fueled fast reactor operating experience,
- Compact reactor operating experience and analytical methods, and
- Light water reactor operating experience.

This operating experience is incorporated throughout the entirety of the Oklo design. For instance, Oklo's decision to use metal fuel was driven largely by the success of Experimental Breeder Reactor II, including its demonstration of inherent safety to shut down the reactor passively. Because of the operating experience of past reactors, the Oklo unit was designed with simplicity, inherent safety, and ease of operation in mind. As a result, Oklo expects to utilize a vastly different and simpler control scheme than past reactors. It is expected that many of the operational experience problems of past reactors will be avoided entirely.

31 RADIATION PROTECTION

31.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(39) requires a description of the radiation protection program. The requirements for the radiation protection program are provided in 10 CFR 20.1101, "Radiation protection programs," which states:

> (a) Each licensee shall develop, document, and implement a radiation protection program commensurate with the scope and extent of licensed activities and sufficient to ensure compliance with the provisions of this part. (See § 20.2102 for recordkeeping requirements relating to these programs.)
>
> (b) The licensee shall use, to the extent practical, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA).
>
> (c) The licensee shall periodically (at least annually) review the radiation protection program content and implementation.
>
> (d) To implement the ALARA requirements of § 20.1101 (b), and notwithstanding the requirements in § 20.1301 of this part, a constraint on air emissions of radioactive material to the environment, excluding Radon-222 and its daughters, shall be established by licensees other than those subject to § 50.34a, such that the individual member of the public likely to receive the highest dose will not be expected to receive a total effective dose equivalent in excess of 10 mrem (0.1 mSv) per year from these emissions. If a licensee subject to this requirement exceeds this dose constraint, the licensee shall report the exceedance as provided in § 20.2203 and promptly take appropriate corrective action to ensure against recurrence.

For the purposes of this pilot, Oklo is analyzing radiation protection only for normal operation. Therefore, the following considerations have been used for the development of this preliminary radiation protection program:

- Only radiation exposure resulting from normal operations is considered, and the
- Only source of radioactivity is the irradiated fuel in the core.

This section is informed by Regulatory Guide 1.206, "Combined license applications for nuclear power plants[28]," and NEI 07-03A, "Generic FSAR template guidance for radiation protection program description," issued in May 2009.

[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

[28] Specifically, the version issued in June 2007 is used.

31.1 Introduction

The objective of the Oklo radiation protection program is to ensure the effective monitoring and control of internal and external doses to onsite personnel, the public, and of releases to the environment, keeping radiation exposures as low as reasonably achievable (ALARA). In order to ensure safety and productivity of the Oklo plant, a radiation protection program is implemented and designed to be within accordance of federal safety standards minimizing radiation exposure to the onsite personnel and to members of the public.

31.2 Plant Sources During Normal Operations

The design of the Oklo reactor ensures that all sources of radiation are contained{ [redacted] }{(i)-(xi)}. For an in-depth discussion on radioactive sources and radioactive materials produced during operation reference Section 3. {

31.2.1 [redacted]

[redacted]

31.2.2 [redacted]

[redacted]

31.2.3 [redacted]

[redacted]

31.2.4 [redacted]

[redacted] }{(i)-(xi)}{eci}

31.3 Radiation Zoning

A "radiation area" is defined in 10 CFR 20.1003, "Definitions," as, "an area accessible to individuals, in which radiation levels could result in an individual receiving a dose equivalent in excess of 0.005 rem (0.05 mSv) in 1 hour at 30 centimeters from the radiation source or from any surface that the radiation penetrates."

Because of the layout and design of the Oklo plant and reactor, there is no accessible area of the Oklo plant that qualifies as a radiation area.

31.4 Shielding Design

31.4.1 Design Objectives

The primary design objective of shielding design is to limit onsite and offsite radiation exposure. The radiation shielding is also used to keep radiation doses to equipment and enclosures below a level at which embrittlement and radiation damage can occur.

The following considerations are used in the developing of the shielding design:

- All sources of radioactivity are identified and shielded based on exposure level requirements for personnel, material, and equipment limits,
- Normal operation conditions are considered to ensure that the shielding analysis is conservative,
- Shielding design is based on neutron and gamma flux originated in the fuel,
- Shielding configurations are designed such that radiation streaming pathways through the shielding are limited,
- Penetrations are located in such a way that radiation streaming is limited,
- Shielding is provided to permit access and occupancy of plant areas where needed, and
- Secondary radiation from material interaction and activation of core components are included.

31.4.2 Analytical Tools

The radiation shielding thicknesses were determined using shielding data and proven radiation transport codes. Oklo used Serpent to model the neutron and gamma flux spectrum of the core. Serpent is a multi-purpose three-dimensional continuous-energy Monte Carlo particle transport code as is discussed in more detail in Section 2.1.2.

Oklo uses Monte Carlo N-Particle (MCNP) version 6.2 to benchmark the findings in the Serpent models. MCNP is a general-purpose Monte Carlo particle transport code that can be used for neutron, photon, electron, or coupled neutron, photon, or electron transport. The code treats an arbitrary three-dimensional configuration of materials in geometric cells and is described in further detail in Section 2.1.2.

The fluence found from these codes was used to determine the activation of materials of interest and assure that adequate shielding was implemented to maintain exposure standards and material limits.

Cross section data used in the analysis are from the ENDF-VII library [32]. Los Alamos National Laboratory invests substantial effort to ensure that production releases of MCNP and MCNP data libraries have undergone rigorous testing, verification, and validation [33].

31.4.3 Plant Shielding Placement

Plant areas that are accessible during normal operation are shielded from radiation to ensure that the dose seen in these areas are as low as reasonably achievable and within the limits set in 10 CFR Part 20, "Standards for protection against radiation," as well as utilizing other sources [34]. [redacted] {(i)-(xi)}

The following sections describe areas in the Oklo design where shielding has been placed. {

31.4.3.1 [redacted]

[redacted]

31.4.3.2 [redacted]

[redacted]

31.4.3.3 [redacted]

[redacted]

[redacted]

Figure 31-1. [redacted]

[redacted]

31.4.3.4 [redacted]

[redacted]

31.4.3.5 [redacted]

[redacted] {(i)-(xi)}{eci}

31.5 Annual Radiation Dose

An annual radiation dose assessment is not included for this pilot. [redacted] {(ii)-(iv), (vi), (ix)-(xi)} The dose assessment for the design basis accident is included in Section 5.

31.6 Operational Radiation Protection Program

A thorough radiation protection program will be developed, documented, and implemented through plant procedures that address quality requirements commensurate with the scope and extent of licensed activities. For purposes of this pilot, the operational radiation protection program is summarized.

In accordance with 10 CFR Part 20, Subpart B, "Radiation protection programs," the purpose of the radiation protection program is to maintain occupational and public doses below regulatory limits and ALARA. To achieve this, the program will include the following:

- A documented management commitment to keep exposures ALARA,
- A trained and qualified organization with sufficient authority and well-defined responsibilities, and
- Adequate facilities, equipment, and procedures to effectively implement the program.

31.6.1 Management

The preparation, audit, and review of the Operational Radiation Protection Program are the responsibility of Oklo management. The Oklo management will establish a policy that is committed to the following:

- Assure that the Oklo facility is designed, constructed, and operated such that operational and public radiation exposures and releases of licensed radioactive materials are ALARA,
- Comply with radiation requirements, dose limits, and limits on release of radioactive materials,
- Implement and maintain a radiation protection program to keep radiation doses below the regulatory limit and ALARA,
- Assure that each individual working at the facility understands and accepts the responsibility to follow radiation protection procedures and instructions provided by radiation protection staff and to maintain his or her dose ALARA,
- Provide delegable authority to stop work or order an area evacuated (in accordance with approved procedures) when, in the judgement of the Oklo Management, the radiation conditions warrant such an action and such actions are consistent with plant safety, and
- Establish an appropriate and direct reporting chain.

31.6.2 Organization

Oklo expects to have a radiation protection team who have the direct responsibility for assuring adequate protection of the health and safety of onsite personnel and members of the public during all aspects of activities. Specific radiation protection responsibilities for the radiation protection team include the following:

- Establish, implement, and enforce the radiation protection program, practices and procedures,
- Track and analyze trends in radiological surveillance reports performed by onsite monitoring systems and take necessary action to correct adverse trends,
- Ensure that exposures to site personnel are maintained ALARA,
- Assure that site personnel are properly trained on radiation protection, and
- Support timely corrective action of radiation protection problems.

The organization, qualification, and training criteria for site personnel are described in Section 19 and Section 26. Onsite personnel will be responsible for providing site-specific radiological information and ensuring that best radiation practices and procedures are employed at the facility. [redacted]

- [redacted]
- [redacted]
- [redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

31.6.3 Facilities, Instrumentation, and Equipment

Adequate facilities, instrumentation, and equipment are provided to support implementation of the radiation protection program during routine operations. {

31.6.3.1 [redacted]

[redacted]

31.6.3.2 [redacted]

[redacted]

[redacted]

31.6.3.3 [redacted]

[redacted] {(i)-(xi)}

31.6.4 Procedures

Radiation protection procedures are not within the scope of this pilot.

32 FIRE PROTECTION PROGRAM

Title 10 to the Code of Federal Regulations (CFR) Section 52.79(a)(40) requires, "A description of the fire protection program required by § 50.48 of this chapter and its implementation."

Oklo is not piloting this section.

33 RISK REDUCTION FROM ANTICIPATED TRANSIENTS WITHOUT SCRAM

33.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(42) requires information demonstrating how the applicant will comply with the requirements of 10 CFR 50.62 for reduction of risk from anticipated transients without scram (ATWS) events. This section defines an ATWS as, "an anticipated operational occurrence as defined in appendix A of this part followed by the failure of the reactor trip portion of the protection system specified in General Design Criterion 20 of appendix A of this part." Further, Appendix A, "General design criteria for nuclear power plants," to 10 CFR Part 50 defines anticipated operational occurrences (AOOs) as, "those conditions of normal operation which are expected to occur one or more times during the life of the nuclear power plant and include but are not limited to loss of power to all recirculation pumps, tripping of the turbine generator set, isolation of the main condenser, and loss of all offsite power."

Because AOOs are conditions of normal operation, they are evaluated for purposes of this pilot. Specifically, this analysis is included in Section 4.

The purpose of this section is to evaluate the applicability of 10 CFR 52.79(a)(42) to the Oklo design.

33.1 Evaluation

Requirements in 10 CFR 50.62 include systems and equipment specifically directed towards light water reactors (LWR). Because Oklo is not an LWR, these requirements are not applicable. [redacted]}{(ii)-(iv), (vi), (ix)-(xi)} For more information on the classification of structures, systems, and components (SSCs) for the Oklo design, see Section 5.

34 CRITICALITY ACCIDENTS

34.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(43) requires that the applicant for a combined license complies with the criticality accident requirements of 10 CFR 50.68, "Criticality accident requirements." Section 50.68 to 10 CFR further references 10 CFR 70.24, "Criticality accident requirements," which discusses maintaining a monitoring system to detect accidental criticality. Paragraph b to 10 CFR 50.68 also places limits on the quantity of special nuclear material (SNM) and other nuclear fuel stored onsite, provides for radiation monitors in storage and handling areas when fuel is present, and limits the enrichment of fresh fuel assemblies. Section 70.24 to 10 CFR specifies a monitoring system with audible alarm shall maintained in areas used to handle, use, or store SNM; the monitoring system shall be capable of detecting a criticality that would not result in exceeding a specified dose. The applicant shall also maintain emergency procedures in case of an alarm and the means to identify, decontaminate, transport, and treat by qualified medical personnel individuals affected by a criticality accident.

The purpose of this section is to provide an overview of how criticality accidents are precluded at the Oklo site.

34.1 Evaluation

34.1.1 Detection or Prevention of Criticality

During normal operation, the Oklo plant does not use, store, or handle new or spent fuel except that which is contained inside the core of the Oklo reactor. The core reactivity control systems are described in Section 2.1.4 and Section 2.4.3. Since all fuel onsite is contained in the reactor module, the Oklo plant does not use new or spent fuel storage rack. Thus, subcriticality is automatically ensured and no criticality monitoring system is needed.

34.1.2 Radiation Monitoring and Accident Response

Since during normal operation the Oklo plant does not use, store, or handle new or spent fuel except that which is contained inside the core of the reactor, no radiation monitoring or accident response requirement specifically for criticality accidents is applicable. See Section 31 for a description of the Oklo radiation protection program.

34.1.3 Repair Operations

In the event a repair is undertaken that necessitates performing fuel handling operations outside the reactor module, appropriate precautions shall be taken to prevent creation of a critical mass, and to monitor for radiation in storage and handling areas. [redacted] {(i)-(xi)}{eci}

35 FITNESS-FOR-DUTY PROGRAM

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(44) requires that a description of the fitness-for-duty program required by 10 CFR Part 26, "Fitness for duty programs," and its implementation be provided.

Oklo is not piloting this section.

36 MINIMIZATION OF CONTAMINATION

36.0 Purpose and Scope

Title 10 to the Code of Federal Regulations (10 CFR) 52.79(a)(45) requires a description of the facility design and procedures that minimize contamination during operation. Specifically, the requirements for minimizing contamination are provided in 10 CFR 20.1406, "Minimization of contamination," which states:

(a) Applicants for licenses, other than early site permits and manufacturing licenses under part 52 of this chapter and renewals, whose applications are submitted after August 20, 1997, shall describe in the application how facility design and procedures for operation will minimize, to the extent practicable, contamination of the facility and the environment, facilitate eventual decommissioning, and minimize, to the extent practicable, the generation of radioactive waste.

(b) Applicants for standard design certifications, standard design approvals, and manufacturing licenses under part 52 of this chapter, whose applications are submitted after August 20, 1997, shall describe in the application how facility design will minimize, to the extent practicable, contamination of the facility and the environment, facilitate eventual decommissioning, and minimize, to the extent practicable, the generation of radioactive waste.

(c) Licensees shall, to the extent practical, conduct operations to minimize the introduction of residual radioactivity into the site, including the subsurface, in accordance with the existing radiation protection requirements in Subpart B and radiological criteria for license termination in Subpart E of this part.

The purpose of this section is to provide an overview of how contamination will be minimized for the Oklo site and is informed by NEI 08-08A, "Generic FSAR Template Guidance for Life Cycle Minimization of Contamination," issued October 2009. The following considerations have been used for the development of this preliminary minimization of contamination analyses:

- All sources of radiation are contained and controlled inside the reactor enclosures, which are inaccessible during normal operations, and
- All materials inside the reactor enclosures are considered activated due to exposure to the core radiation field.

For purpose of this pilot, only normal operating conditions are considered. Future work will include other operating conditions as well the discussion of any potential waste handling onsite.

Contamination control design features are established to assure compliance with 10 CFR Part 20, "Standards for protection against radiation," and to prevent the unauthorized release of radioactive materials to unrestricted areas. Deterministic radioactive release scenarios are modeled and presented in Section 5.

36.1 Minimization of Facility Contamination

36.1.1 Facility Layout

The Oklo facility layout is designed in such a way that radiological materials are only present and are fully contained in the reactor enclosures, which are inaccessible during normal operations. Radiation detection monitors are located throughout the facility to ensure early detection of any potential failures in the enclosures.

36.1.2 Design Features of Structures, Systems, and Components

The structures, systems, and components (SSCs) of the Oklo plant are designed such that all radiological materials produced in the reactor are contained inside the reactor enclosures at all times during normal operations. Expected radiological materials produced during operation and how these materials are controlled is further discussed in detail in Section 3. No other radioactive materials will be stored on site.

The unique SSCs in the Oklo design, which are described in Section 2, minimize the need for fluids that could leak or spill. The below sections discuss areas in the Oklo plant that contain fluids.

36.1.2.1 Power Conversion System

The only fluid that enters or exits the reactor enclosures is the power conversion system coolant. Due to the location and shielding of the power conversion system coolant, it is expected to receive little or no activation. Detection methods for the leak of the power conversion system coolant will be implemented but not for radiological purposes.

36.1.2.2 Reactor Enclosures

The reactor enclosures are backfilled with an inert gas. The reactor enclosures by design are not considered leak tight. However, as described in Section 3, the gas exposed to the core radiation flux is expected not to activate to significant levels, remaining below the regulatory standards for effluents as set in 10 CFR Part 20.

36.1.3 Prompt Detection of Leakage

36.1.3.1 Routine Monitoring or Surveillance

As stated, the design of the Oklo reactor has reduced the potential leak sources to two systems: the power conversion system, and the reactor enclosures. The access areas of these systems will be continuously monitored with detectors placed in close proximity to penetrations and potential leak points. [redacted] {(ii)-(iv), (vi), (ix)-(xi)}

36.1.3.2 Ground Water Monitoring Program

The Oklo reactor has been designed to preclude any potential contamination of ground water on the site. [redacted]

[redacted]}(ii)-(iv), (vi), (ix)-(xi)} Given the reactor's small size and low power level, even if contamination or activation were to theoretically occur, the resulting levels would still be expected to remain below relevant limits. [redacted]}(ii)-(iv), (vi), (ix)-(xi)}

36.2 Minimization of Potential of the Release of Contamination from Undetected Leaks

The SSCs that are potential sources of leaks have been situated in locations that ensure easy detection of leaks, therefore, undetected leaks are unlikely at the Oklo site.

36.3 Reducing the Need for Decontamination

The following have been considered and implemented to reduce the need for decontamination:

- Total facility size is small, and most facility components do not contain radioactive or activated materials,
- Periodic inspection and testing of SSCs takes place, and
- Application of quality control procedures during installation of components with the potential for activation or that contain radioactive or activated materials.

Implementing the above considerations minimizes the potential for contamination, and in turn the need to decontaminate components of the facility during normal operations.

36.4 Operational Practices

The site procedures and practices that keep onsite exposures as low as reasonably achievable decreases the probability of a release, the amount released, and the spread of contaminants. Onsite personnel do not under normal operating conditions access airborne or otherwise contaminated radioactive areas. [redacted]}(ii)-(iv), (vi), (ix)-(xi)} Contamination of individuals is unlikely even during emergency situations, therefore, discussion of decontamination will be provided at a later date if necessary.

36.5 Minimization of Contamination of the Environment

As stated in NEI 08-08A, "A 'credible mechanism' for the licensed material to reach ground water is considered one wherein the failure of a single barrier between the SSC and the environment that could result in inadvertent or unintentional contamination of ground water or native soil." The design of the Oklo reactor and materials chosen to ensure that there are no credible mechanisms that are possible. Multiple barriers exist between significant sources of radioactive material (i.e., the fuel and fission products generated during operation) and the environment. [redacted]}(i)-(xi)}(eci) Thus, far more than a single barrier failure would be required for contamination to result.

36.6 Facilitation of Decommissioning

The decommissioning of the Oklo plant is outside the scope of this pilot.

37 AIRCRAFT IMPACT ASSESSMENT

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.79(a)(47) requires compliance with 10 CFR 50.150, "Aircraft impact assessment." Specifically, 10 CFR 50.150 (the "AIA rule") requires applicants to conduct an aircraft impact assessment (AIA) that shows that, with reduced use of operator actions:

- The reactor core remains cooled, or the containment remains intact, and
- Spent fuel cooling or spent fuel pool integrity is maintained.

For the purpose providing implementing guidance for the AIA Rule, NEI developed NEI-07-13, "Methodology for Performing Aircraft Impact Assessments for New Plant Designs" [35]. The guidance document was a collaborative NRC/NEI effort and considered insights gained from NRC and industry assessments of operating and new reactor designs.

In 2011, NRC issued RG 1.217, "Guidance for the Assessment of Beyond-Design-Basis Aircraft Impacts", which wholly-endorsed NEI 07-13 as an acceptable method for performing aircraft impact assessments and satisfying required NRC regulations (i.e., 10 CFR 50.150). Together these documents are considered the "AIA guidance." Since 2009, all new reactor designs have referenced RG 1.217 and NEI 07-13 as the method for performing aircraft impact assessments.

37.0 Beyond Design Basis Consideration

The impact of a large, commercial aircraft is a beyond-design-basis event and the stringent requirements that apply to the design, construction, testing, operation, and maintenance of design features and functional capabilities for design basis events do not apply [36]. This position is based, in part, on results of NRC aircraft impact studies performed in response to the September 2001 events. These detailed studies confirmed the low likelihood of an aircraft impact both damaging the reactor core and releasing radioactivity that could affect public health and safety as described for design basis threats in 10 CFR 73.

In a July 2008 letter to the NRC Chairman (Dale E. Klein), the Advisory Committee on Reactor Safeguards (ACRS), concluded it is appropriate to treat aircraft attacks as beyond-design-basis events [36]. Similarly, in its Staff Requirements Memorandum (SRM) approving the AIA Rule, the NRC Commission agreed that the impact of a commercial airliner is a beyond-design-basis event and therefore not necessary for reasonable assurance of adequate protection to public health and safety [37].

37.1 Oklo Plant Design

37.1.1 Building

The Oklo reactor is intended for relief for high power cost area microgrids. The design does not require a large site or building complex. [redacted] {(i)-(xi)}

37.1.2 Systems below grade

[redacted]} {(ii)-(iv), (vi), (ix)-(xi)} Additionally, the core of the Oklo reactor is contained within enclosures below grade. As such, according to RG 1.217, these systems are not directly hittable by a large commercial aircraft, traveling at high speed, and impacting at a shallow approach angle, such as that used for the September 2001 Pentagon attack. RG 1.217 and NEI 07-13 describe that below grade structures, systems, and components are not susceptible to direct aircraft impact damage. Table 37-1, below, provides a comparison of safety-related systems locations for typical operating and new reactor designs.

Table 37-1. Reactor types and safety systems which are above grade and hittable

Reactor Design	Safety Systems Located Above Grade and Hittable?
Typical BWR Mark 1 Reactor Building	Yes
Typical PWR Containment	Yes
AP1000 (Shield Building Only)	Yes
APR1400 Containment	Yes
ESBWR Reactor Building	Yes
NuScale Reactor Building	Yes
Oklo Design	No

37.2 Hittable Buildings

The determination of whether a targeted building is hittable by an aircraft is dependent upon factors such as building size as well as the size, speed, and angle of approach of the attacking aircraft.

37.2.1 Aircraft Controllability

The large size and high-speed capability of commercial aircraft make them ideal for imparting significant damage to large ground targets. However, these same attributes make it difficult to control the large aircraft, at high-speed, to target and hit a smaller ground target.

Federal Aviation Administration guidance for pilots has shown that controlling a large commercial aircraft, at a high speed and near the ground surface, is complicated due to the presence of ground effects [38]. These effects typically occur within a height above the ground that is less than the wingspan of the aircraft and can result in rapid changes to the lift and drag forces acting on the wings; thus necessitating pilot corrective actions. These corrective actions can be complicated by the slow response of a large aircraft (due to large size and weight), and make it difficult for the aircraft, traveling at high speed, to hit a small target on the ground. See Table 37-2 for example aircraft parameters.

Table 37-2.. Characteristic parameters for commercial aircraft

	Boeing 757	Boeing 767
Gross Weight (lb)	255,000	300,000
Passenger Capacity	>200	>200
Wing Span (ft)	124	156

Fuselage Length (ft)	155	159
Fuselage Diameter (ft)	12	16
Range (miles)	>3,200	>3,800
Maximum Cruise Speed (mph)	>500 mph	>550 mph

To address the issue of reduced controllability, the AIA Rule describes that the impact speed and angle of impact considering the ability of both experienced and inexperienced pilots to control large, commercial aircraft at the low altitude representative of a nuclear power plant's low profile should be considered.

37.2.2 Building Characteristics

The September 11, 2001 events involved malevolent aircraft attacks on large iconic buildings. Each of the targeted World Trade Center buildings had a projected side area that exceeded 58,000 ft^2, as shown in Table 37-3 [39], [40]. A review of various existing and new reactor plant buildings was performed, using publicly available design information, to identify the ranges of typical building sizes, as shown in Table 37-4. The review focused on side profiles of buildings because, in accordance with AIA guidance, roof impacts do not need to be explicitly considered. The building widths listed in Table 37-4 are conservatively based on minimum building dimensions and, in some cases such as the AP1000, the projected side areas do not account for adjacent buildings such as an auxiliary building. The results indicate that the projected side area for typical operating BWR and PWR plant buildings range from 19,600 ft^2 to 24,000 ft^2 and the projected side area for new reactor plant buildings ranges from 12,190 ft^2 to 36,190 ft^2.

Table 37-3. Dimensions and projected areas of buildings impacted by malevolent aircraft impact

	World Trade Center 1	World Trade Center 2	Pentagon
Width (ft)	210	210	922 (single side)
Height (ft)	1368	1362	63
Projected Area (ft^2)	287,280	286,020	58,086

Table 37-4. Dimensions and projected areas of relevant plant buildings

Design	Width (ft)	Height (ft)	Projected Side Area (ft^2)
Typical BWR Mark 1 Reactor Building	150	160	24,000
Typical PWR Containment	140	140	19,600
AP1000 Shield Building	143	227	32,461
APR1400 Containment	154	235	36,190
ESBWR Reactor Building	160	157	25,120
NuScale Reactor Building	150.5	81	12,191

[redacted]

[redacted]

Figure 37-1. [redacted]

}{(ii)-(iv), (vi), (ix)-(xi)}

37.3 Aircraft Impact Analysis for the Oklo Design

This assessment was done in evaluation of the Oklo design against 10 CFR 50.150 to ensure that it meets the first requirement, from 10 CFR 50.150(a)(1)(i). Several design features of the Oklo reactor are conducive to meeting this requirement, including:

- The reactor module is located fully below grade, and covered with a thick concrete pad,
- The reactor module presents a comparably small target.

Because the reactor module is fully below grade, guidance from RG 1.217 and NEI 07-13 describe that below grade structures, systems, and components are not susceptible to direct aircraft impact damage. [redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Although the reactor is fully below grade, an assessment of hittable portions was outlined. [redacted]}{(ii)-(iv), (vi), (ix)-(xi)}

Based on the above observations, and based on the existing NRC guidance, it is judged that an impact by a high-speed, large commercial aircraft is neither a credible nor a realistic event, and that because the reactor module is fully below grade, even if an aircraft impact were to occur, the reactor would not be susceptible to aircraft impact damage. As such, the requirement in 10 CFR 50.150(a)(1)(i) is met by default.

Because Oklo does not store spent fuel onsite, the requirement in 10 CFR 50.150(a)(1)(ii) is met by default.

OKLO

III. Proposed ITAAC

1 PURPOSE AND SCOPE

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.80 requires applicants for a combined license to submit inspections, tests and analysis acceptance criteria (ITAAC). Section 52.80(a) to 10 CFR specifies:

> (a) The proposed inspections, tests, and analyses, including those applicable to emergency planning, that the licensee shall perform, and the acceptance criteria that are necessary and sufficient to provide reasonable assurance that, if the inspections, tests, and analyses are performed and the acceptance criteria met, the facility has been constructed and will be operated in conformity with the combined license, the provisions of the Act, and the Commission's rules and regulations.

Oklo is not piloting this section. However, it is expected that {[redacted]}{(ii)-(iv), (vi), (ix)-(xi)} inherent safety characteristics will dictate therefore that the level of detail required in ITAAC for this design will be substantively less than previous designs, and that the Oklo quality assurance program will serve to assure that structures, systems and components (SSCs) are manufactured and will function in conformity with bounds shown for analyses and data provided in the application for the combined license.

IV. Environmental Report

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1 PURPOSE AND SCOPE

Title 10 to the Code of Federal Regulations (10 CFR) Section 51.50(c) requires applicants for a combined license to submit an environmental report. Section 51.50(c) to 10 CFR requires that combined license applicants submit an environmental report that contains the information specified in 10 CFR 51.45, "Environmental report," 10 CFR 51.51, "Uranium fuel cycle environmental data," and 10 CFR 51.52, "Environmental effects of transportation of fuel and waste." This initial environmental report does not address 10 CFR 51.51 nor 10 CFR 51.52.

The purpose of this initial environmental report is to provide preliminary analysis and approach for the Oklo design for compliance with 10 CFR 51.45 and in order to pilot possible impact of principles of risk-informing from DG-1353 on various portions of an application and application structure. Specifically, the information contained in this section applies generically for Oklo reactors, regardless of where they are located.

The information presented in this section and the structure within the information is presented is largely informed by draft regulatory guide (DG)-4026, "Preparation of Environmental Reports for Nuclear Power Stations" [41]. However, several modifications are made from the proposed structure of DG-4026 to better streamline the information presented. Section 2 of this report, "Facility Layout and Project Description," parallels Section 3 from DG-4026; this section is moved up to provide an initial idea of the characteristics of the Oklo site, which stand in stark contrast to those of traditional large light water reactors. Section 3 of this report, "Existing Site and Projected Impacts," combines Sections 2, 4, 5, 6, and 7 from DG-4026; these section are consolidated to combine relevant information on individual environmental resources into contiguous sections, rather than splitting similar information over multiple chapters as presented in DG-4026. Section 4, "Project Justification," combines Sections 8 and 9 from DG-4026; with this restructured approach, the discussion of the need for the proposed project can be directly compared and contrasted with the alternatives currently or potentially available.

2 FACILITY LAYOUT AND PROJECT DESCRIPTION

2.0 Facility Layout

An Oklo plant likely will include only a single building on the site. [redacted]}(i)-(xi)}(eci}. The site boundary is assumed to be 100 m from the building for the present analysis but will likely be smaller for future analyses.

2.1 Project Description

Construction is one of the biggest challenges for a typical nuclear power plant, as with any large-scale infrastructure project. Light water reactors face particular construction challenges, including:

- The concrete containing structure, which is very large and must be constructed to stringent nuclear quality assurance standards,
- The logistical challenges of transporting and installing large components such as pressure vessels and steam generators, and
- The staffing issues inherent in training and maintaining thousands of high quality construction personnel onsite.

Further, construction is defined in *Title 10 to the Code of Federal Regulations* (10 CFR) Section 51.4, "Definitions," to include the following:

> (i) Activities constituting construction are the driving of piles, subsurface preparation, placement of backfill, concrete, or permanent retaining walls within an excavation, installation of foundations, or in-place assembly, erection, fabrication, or testing, which are for:
>
> > (A) Safety-related structures, systems, or components (SSCs) of a facility, as defined in 10 CFR 50.2;
> >
> > (B) SSCs relied upon to mitigate accidents or transients or used in plant emergency operating procedures;
> >
> > (C) SSCs whose failure could prevent safety-related SSCs from fulfilling their safety-related function;
> >
> > (D) SSCs whose failure could cause a reactor scram or actuation of a safety-related system;

(E) SSCs necessary to comply with 10 CFR part 73;

(F) SSCs necessary to comply with 10 CFR 50.48 and criterion 3 of 10 CFR part 50, appendix A; and

(G) Onsite emergency facilities (*i.e.*, technical support and operations support centers), necessary to comply with 10 CFR 50.47 and 10 CFR part 50, appendix E.

Considering the 10 CFR 51.4 definition of "construction," the Oklo site largely does not experience construction. Many of the items listed under construction in 10 CFR 51.4 relate to safety-related SSCs{[redacted] }{(ii)-(iv), (vi), (ix)-(xi)}. For items in the 10 CFR 51.4 definition that do not concern safety-related SSCs (e.g., security-related SSCs, fire protection-related SSCs, emergency preparedness SSCs), there will likely be no activities required for these items that are similar to driving of piles, subsurface preparation, placement of backfill, concrete, or permanent retaining walls within an excavation, or installation of foundations. For the items listed in the construction definition in paragraphs E-G, there will likely be placement of already manufactured SSCs, which may comprise the short construction period of the Oklo plant. Therefore, "construction" for the Oklo site is discussed as "site preparation."

Site preparation at the Oklo site is much simpler than construction of a typical light water reactor, at least commensurate with its much smaller size (i.e. 500 times smaller than a typical light water reactor). The majority of the components are factory constructed, and their small size does not present significant logistical challenges. The Oklo design does not have components that cannot be transported by truck or that cannot be lifted by readily available cranes, unlike some components large light water reactors. The onsite work consists primarily of site preparation work, and installation of the factory-constructed components.

[redacted] }{(ii)-(iv), (vi), (ix)-(xi)} The site boundary is taken at a distance of 100 m from the site building for radiological dose calculation purposes (as shown in Section 5 of the Final Safety Analysis Report), with the expectation that additional analyses will reduce this distance significantly. The area that will require some degree of preparation will be limited to essentially that of the building area, plus some additional area for parking, roads, and space used during site preparation. {[redacted] }{(ii)-(iv), (vi), (ix)-(xi)} The Oklo site's small disturbed footprint relative to typical large nuclear power plants results in substantially smaller impact to the surrounding environment.

[redacted]

[redacted] {(i)-(xi)}

Draft regulatory guide (DG)-4026, "Preparation of Environmental Reports for Nuclear Power Stations," refers to land areas in terms of the site, vicinity, and region. In this pilot document, Oklo defines the Oklo site as the disturbed area, which encompasses the building and the parking, plus the small additional area temporarily disturbed during site preparation and a small additional area of buffer space. The vicinity and region are defined as all areas outside of the site.

The only water usage will be for potable and sanitary water [redacted]}{(ii)-(iv), (vi), (ix)-(xi)}. Based on United States Geological Survey per capita residential water usage estimates, the Oklo installation is expected to use less than 200 gallons/day [42]. Where available, the Oklo site will be connected into local municipal water districts to supply this demand.

Staffing during site preparation and reactor installation will be orders of magnitude lower than required for a typical large nuclear power plant construction project. As described above, the site preparation work is small scale and straightforward, and the components to be installed are factory-constructed and delivered to the site with minimal assembly required. Staffing numbers will be at predictable levels and potentially decrease as experience is gained at each new reactor site due to the standardized nature of the site. Due to these low staffing requirements it is estimated that site preparation traffic will not have significant impacts on local infrastructure.

3 EXISTING SITE AND PROJECTED IMPACTS

3.0 Introduction

Draft regulatory guide (DG)-4026, "Preparation of Environmental Reports for Nuclear Power Stations," suggests a description of the existing site, and the impacts of construction and operation of the proposed plant, with specific focus on the following categories:

- Land use,
- Water resources,
- Ecological resources,
- Socioeconomics,
- Environmental justice,
- Historic and cultural resources,
- Air resources,
- Nonradiological health, and
- Radiation environment and radiological monitoring.

In this environmental report, each of these categories are evaluated for their applicability to the Oklo design. Given the small size and simplicity of the Oklo site, and the comparatively fast site preparation, many of the specified categories are not expected to be significantly impacted. As such, detailed information relating to these categories is not provided in the below sections. For categories judged to be impacted by the Oklo design, this section presents generic or bounding details about the approach Oklo will take to provide the relevant site and projected impact information.

3.1 Land Use

3.1.1 Site, Vicinity, and Region

3.1.1.1 Site Area Map

A description of the Oklo site is presented in Section 2.1 of this report and Section 1 of the Final Safety Analysis Report. As the generic site layout is expected to be applicable across sites, it will remain unchanged and representative of a bounding case regardless of the selection of a particular site. Once a particular site has been selected, a map presenting the general outlines of that site will be included in the final application.

3.1.1.2 Zoning Information

The Oklo site will obey all applicable zoning laws for a particular site's selection. Once a particular site has been selected, the relevant zoning information will be included.

3.1.1.3 Maps and Summary Tabulation of Areas Occupied by the Principal Land Uses for the Site, Vicinity, and Region

The Oklo site will not occupy a significant land area (as discussed in Section 2.1). Additionally, the Oklo reactor's short site preparation and small size once complete is not expected to have an impact on the surrounding land use areas. As such, detailed information concerning land use areas surrounding the site will not be provided.

3.1.1.4 Maps Showing Highways, Railroad Lines, Waterways, and Utility Corridors Located on, or That Cross, the Site, Vicinity, and Region

During site preparation, the Oklo site will receive shipments of completed components and raw materials that are shippable via semitruck, yet may require some special considerations based on the components' size such as oversize load transport. As such, information concerning the relevant nearby transportation corridors likely to be affected by these shipments will be included. Given the small number of components that will require such accommodations, the overall impact and corresponding level of description detail will be nominal. Once completed, the Oklo site is not expected to have an impact on these adjacent transportation arteries due to its small overall size and intrinsic safety which negates need for an exclusion area or offsite emergency planning zone.

3.1.1.5 Map Showing the Existing Topography of the Site and Vicinity

The Oklo reactor will require minimal topographical adjustment to make it suitable for installation. Particularly, no topographical adjustment is expected to have any safety-related impacts on installation. As such, existing topographical information will be excluded as the expected impact of the proposed action will be minimal. If, however, topographical adjustments are expected to be significant, information concerning these adjustments will be provided.

3.1.1.6 Special Land Use Areas That Could be Affected by the Project

Special land use areas include recreation areas, parks, tribal lands, designated wild and scenic rivers, or areas of other special designation. The Oklo site will generally not be located directly in any of these special land use areas, and as such information concerning these areas will only be provided in the case where the site does occupy an area meeting this definition. Given its minimal offsite impacts, information concerning offsite special land use areas will not be provided.

3.1.1.7 Raw Material Resources and Owners Thereof on or Adjacent to the Site That Are Presently Being Extracted or Are of Known Commercial Value

The Oklo site is small enough that the presence of the site itself will not preclude resource extraction from deposits located in the region, whether presently underway or projected. As a result, information on these activities will not be provided.

3.1.1.8 Maps Showing Major Public and Trust Land Areas in the Region

No offsite land areas are anticipated to be significantly affected by the Oklo site, either during site preparation or after operation has commenced. Any major public and trust land areas in the region, will therefore be unaffected, and as such this information will not be provided.

3.1.1.9 Discussion of Whether Any Land at the Proposed Site or Any Affected Offsite Lands Would Be Subject to Requirements in the Coastal Zone Management Act (16 U.S.C. 1451 et. Seq.)

It is unlikely that a site location would be selected such that the site would be subject to the Coastal Zone Management Act. If a particular site is selected that is subject to these requirements, information concerning how the requirements are met by the site will be provided. Since no offsite lands are anticipated to be significantly affected by the Oklo site, information concerning the applicability of these offsite areas to requirements in the Coastal Zone Management Act will not be provided.

3.1.1.10 Discussion of Whether Any Land at the Proposed Site or Any Affected Offsite Lands Constitute Prime or Unique Farmlands (7 CFR 657)

Given the Oklo site's small size, no significant impact on offsite prime or unique farmlands is anticipated regardless of specific site selection. Accordingly, this information will not be provided.

3.1.1.11 Maps and Discussion of Any Floodplains or Wetlands on the Site

The Oklo reactor will be designed to withstand a bounding flooding event that covers any possible event that may be encountered at any particular site location; analysis regarding this event is outside the scope of this pilot. The Oklo reactor will be located such that the affected area of the site is not situated in wetlands. As such, no information on the floodplains or wetlands on the site will be provided.

3.1.1.12 Discussion of Whether the Applicant Intends to Acquire Additional Land to Expand the Proposed Site

Oklo may indeed retain the option to expand any of the sites selected for reactor installations. Since each plant will still be very small in total footprint, the magnitude and impact of such land acquisition will be significantly less than for site expansions at large commercial power reactor facilities. Appropriate details on site expansion will accordingly be provided once a specific site has been selected.

3.1.1.13 Brief Discussion of the Major Geological Aspects of the Site That Could Influence Land Use

The Oklo plant will be designed to withstand a bounding seismic event that will cover a range of potential specific site locations. Information showing that the seismic conditions at a particular site are bounded by this assumed event will be provided, together with other geologic and geotechnical information showing the suitability of the site for the Oklo facility, as appropriate. The Oklo site will be selected so as not to disturb unique geologic features, and as such detailed information on these features will not be provided.

3.1.2 Transmission-Line Corridors and Other Offsite Areas

The Oklo plant is very small in comparison with conventional large light water reactor plants requiring major investments in transmission lines and other offsite areas. The Oklo plant is also similarly sized to many existing electric generating installations, and as such, if it replaces such a facility, it will require few to no changes in the existing transmission line infrastructure. In this case, no information need be provided about transmission line corridors as the Oklo installation will not affect those areas.

For sites at which new transmission lines will need to be constructed, the size and impact of these additional structures will be proportionate to the small size of the Oklo unit, and as such are expected to be minimally disruptive to the surrounding environment. Information concerning the proposed transmission and distribution infrastructure upgrades will be provided in this case, commensurate with the expected impact of the improvements.

3.2 Water Resources

3.2.1 Hydrology

3.2.1.1 Discussion of Rivers and Streams

The Oklo plant will be designed to survive bounding floods applicable across U.S. regions, and as such detailed information concerning the historical flood conditions at a particular site will not be provided; rather, only enough information to demonstrate that the bounding flood is indeed bounding will be provided. In addition, as the Oklo plant rejects heat directly to the atmosphere using air (not evaporative) cooling, it will not be situated directly on the banks of a river or stream and will generally be sited away from these water resources. Since the Oklo site is expected to have a very small impact, given the site characteristics discussed in Section 2.1, no detailed information concerning the rivers and streams that may exist outside the site will be provided.

3.2.1.2 Discussion of Lakes and Impoundments

Similar to the discussion of rivers and streams, since the Oklo plant is not expected to be impacted by or to impact nearby lakes and impoundments, no information concerning these water resources will be provided.

3.2.1.3 Discussion of Estuaries and Oceans

The Oklo plant will not rely on once-through heat rejection to the ocean as an ultimate heat sink, and as such will not be directly situated on the ocean shore. It is unlikely that the Oklo plant will be built in a marine estuary either, since the below-grade emplacement of the reactor unit and the power conversion system would make such an effort difficult and expensive. Since the Oklo plant will not be directly situated on either of these hydrologic features, and will not impact nearby features, no detailed information concerning them will be provided.

3.2.1.4 Discussion of Groundwater

The Oklo plant is designed to have no significant impact on the groundwater characteristics of any selected site. [redacted] {(i)-(xi)}{eci} As a result, since the Oklo plant will have a minimal impact on the groundwater of the immediate site and nearby areas, no detailed information concerning the existing characteristics or the potential effects of the planned installation will be provided.

3.2.1.5 Data Concerning Use of Groundwater Including Drawdown Caused by Withdrawals from Neighboring Major Industrial and Municipal Wells That May Result in the Transport of Material from the Site to These or Other Wells

As discussed above, since the Oklo plant is not expected to affect or be affected by the groundwater resources on or near the site, no detailed information concerning the use of these resources by nearby consumers will be provided.

3.2.1.6 Maps or Figures Showing Information Requested Above, as Appropriate

Since the Oklo reactor is expected to have minimal impact on the water resources of the site and vicinity, only maps showing the basic site layout with water resources depicted (if present) will be provided.

3.2.2 Water Use

As discussed in Section 2.1, the Oklo reactor is conservatively expected to use less than 200 gallons/day, entirely for sanitary and potable uses, based on United States Geological Survey estimates for per-person residential water usage rates [42]. It is expected that in locations where it is available, the Oklo plant will use local municipal water distribution systems to meet its sanitary water supply needs. Where local municipal water supplies are not available, alternative sources will be employed, but with the very small need{[redacted]}{(ii)-(iv), (vi), (ix)-(xi)}, the impact is expected to be minimal. As such, detailed information concerning the local and site-related water uses will not be provided.

3.2.3 Water Quality

Since the Oklo reactor does not have liquid effluents and is thus not expected to impact on-site or local water resource quality, detailed information concerning the water quality characteristics of surface waterbodies, groundwater aquifers, and reclaimed water will not be provided.

3.2.4 Water Monitoring

As discussed in Section 3.2.1, the Oklo reactor does not rely on water intake for cooling purposes and is designed to limit impacts on the site's groundwater. No significant impacts on the immediate groundwater resource or nearby surface water sources are expected. As such, it is unlikely that the Oklo site will employ water monitoring systems, as the atmospheric release monitoring systems are expected to provide adequate information concerning potential unanticipated release of radiological material (no routine radiological material emissions are anticipated during normal operations).

3.3 Ecological Resources

3.3.1 Terrestrial Ecology

3.3.1.1 Terrestrial Habitats

Detailed information concerning the ecoregions encompassed by the vicinity and region will not be provided, due to the small size of the Oklo site as discussed in Section 2.1. An appropriately detailed description of the terrestrial habitat of the site itself will be provided.

3.3.1.2 Wetlands

As discussed in Section 3.2.1, the Oklo plant will not be directly situated in a wetland habitat. As the plant's impact on surrounding areas is minimal, detailed information concerning nearby wetlands will not be provided.

3.3.1.3 Wildlife

The Oklo site's small size and minimal impact preclude large-scale disruption of wildlife. Wildlife will still be allowed to roam over much of the site itself, as the Oklo reactor operation is robust to external factors including potential disruption due to wildlife actions.{ [redacted] } {(i)-(xi)}{eci} As a result, even within the site boundaries, impacts to wildlife will be small and limited to only the site preparation and use of the single on-site building and parking area. Accordingly, detailed information concerning wildlife present on the site will not be provided.

Impacts to wildlife offsite will be limited to only those impacts arising from transmission line construction, for sites without existing transmission infrastructure. As this infrastructure is expected to be appropriately-sized to match the small size of the Oklo plant, it too should have a commensurately minimal impact on wildlife.

3.3.1.4 Discussion of Impacts on Important Species and Habitats

Oklo understands and respects the sensitivity of important species and habitats to disruptions. The primary approach Oklo will take to ensure these disruptions are minimized is to place the site in an area that does not contain any important species or habitats. The Oklo plant's small size and minimal impacts make it easier to simply select such a site, in which case no detailed information concerning these impacts will be provided. In cases where a particular placement does have some possibility of impact, information commensurate with the level of disruption expected from the Oklo installation will be provided.

3.3.2 Aquatic Ecology

As the Oklo installation will not be directly located on a body of water and will have minimal impact on nearby bodies of water (either onsite or offsite), no information concerning the ecology of these aquatic environments will be needed or provided.

3.4 Socioeconomics

As discussed in the Generic Environmental Impact Statement for License Renewal of Nuclear Power Plants, the socioeconomic considerations of nuclear power plants are almost entirely positive [43]. Tax revenues generated from the plant, as well as additional employment, are positive factors associated with the construction of a nuclear power generating facility. Additionally, the Oklo plant is targeted for high cost power areas of the U.S. and as such, the Oklo power plant will result in significant reductions in the cost of electricity, which can significantly increase the standard of living in these communities. The regulations recognize that areas of the U.S. may have particular need for clean and reliable power; according to 10 CFR 50.43 (b), applications for high cost power areas should be given preferred

consideration by the NRC. Section 4 contains additional discussion on the socioeconomic benefits expected to be generated by an Oklo installation.

According to Oklo analysis, costs can reach $5.00/kWh in Alaskan towns and similarly on military bases and islands. In many communities, these high prices force people to migrate to more affordable places, leaving behind their hometown. Communities also face disruptions or total electrical outages due to diesel fuel supply chain interruptions. These risks are compounded by the potential for leaks and spills, which can be particularly devastating in areas reliant on fishing and other wildlife. The Oklo plant is estimated to provide at least a savings of 70% to these areas, achieving payoffs on the investment within a few years of the more than a decade deployment. The ability to have a reliable, clean, and relatively low-cost power supply in remote communities would allow people to remain in their hometowns and maintain their preferred way of life. Additionally, it would provide growth opportunities and allow the local communities to thrive. Ultimately, availability of reliable, clean, and cheaper electricity in remote communities helps to secure their future through energy stability and subsequent economic growth.

3.5 Environmental Justice

The Oklo plant directly serves as a medium by which disadvantaged communities may be better served. Disadvantaged communities are disproportionately impacted by high costs of electricity, as this fixed price of a necessary good must be borne before considering nonessential budget items. By significantly decreasing the cost of electricity, disadvantaged communities can not only save on energy costs, but also afford to consume more, which can serve to increase standards of living.

3.6 Historic and Cultural Resources

Oklo is sensitive to the historic and cultural heritage of potential host locations. An essential component of Oklo's approach to site selection is public outreach. Oklo's sites will be selected in large part on the basis of a community's desire to host the facility and enjoy access to clean and reliable power along with greatly reduced power costs. As the Oklo site will be small, the impact on cultural resources is expected to scale accordingly.

3.7 Air Resources

3.7.1 Climate

[redacted] {(i)-(xi)} More detailed analyses regarding air temperatures will be provided at a later date.

3.7.2 Air Quality

The air rejected by the Oklo reactor's cooling systems is not anticipated to become activated, additionally, it is expected that the existence of the Oklo plant will substantively improve air quality of any community over an alternative fossil plant, and as such, detailed information

concerning the air quality of a particular site will not be provided; more information is located in Section 3 of the Final Safety Analysis Report.

3.7.3 Atmospheric Dispersion

The safety analysis for the Oklo plant assumed conservative conditions that should bound possible behavior at any site selected for an Oklo reactor. The conservatisms assumed were also combined in such a way so as to compound these conservatisms. The atmospheric stability was assumed to be Pasquill class F during the entire period of radionuclide release. The wind speed was taken as 1 m/s, the lowest possible value accepted by the radiological release modeling tool employed. No ground deposition is credited, with 100% of the plume reflecting off the ground and continuing to travel downwind. Plume meander was set to zero (no meander), as was plume rise. Further information on atmospheric dispersion impacts on dose analysis is located in Section 5 of the Final Safety Analysis Report.

3.7.4 Meteorological Monitoring

Oklo may maintain meteorological monitoring stations for investment protection purposes. [redacted] {(ii)-(iv), (vi), (ix)-(xi)} Information related to emergency plans is located in Section 15 of the Final Safety Analysis Report. Further, the installations will not be sensitive to most weather conditions during operation, as the air rejection systems and buildings are designed to operate even in severe weather events.

3.8 Nonradiological Health

3.8.1 Public and Occupational Health

The Oklo reactor is not expected to impact nonradiological human health in any significant way. All applicable federal, state, and local workplace safety laws will be observed onsite at all times. Detailed information on public and occupational health impacts will accordingly not be provided.

3.8.2 Noise

The Oklo site's operating noise level will be minimal [redacted] }{(i)-(xi)}.

3.8.3 Transportation

The Oklo site's operating impact on local transportation is minimal [redacted] }{(ii)-(iv), (vi), (ix)-(xi)}. It is important to note that the Oklo plant is not designed for refueling, which alleviates many concerns associated with transportation.

The greatest impacts on local transportation will come during initial site preparation and during decommissioning. However, given that the Oklo plant's components are generally fabricated at a factory before undergoing final assembly onsite, the amount and length of site preparation will be minimized. Information concerning the Oklo site's impact on local transportation infrastructure during site preparation will be provided, as appropriate.

3.8.4 Electromagnetic Fields

The Oklo site's impact on nonradiological health due to the generation of electromagnetic fields will not be evaluated. As discussed in the Generic Environmental Impact Statement for License Renewal of Nuclear Power Plants, no negative health effects have been definitively or credibly associated with chronic exposure to electromagnetic fields [43]. All areas on the Oklo site where acute electromagnetic fields are generated are inaccessible during normal operations.

3.9 Radiological Environment and Radiological Monitoring

The Oklo site will have radiological monitoring systems in place to detect abnormal releases of radionuclides. However, given that even accidents with significant core damage fractions result in radionuclide releases whose dose is an order of magnitude below relevant regulatory limits (see Section 5 of the Final Safety Analysis Report), and releases during normal operation are expected to be negligible (see Section 31 of the Final Safety Analysis Report), the impact of the Oklo reactor on the radiological environment is expected to be minimal to none and a commensurate amount of information concerning the preexisting radiological environment and the proposed monitoring system will be provided as a result.

3.10 Cumulative Impacts

Because the positive environmental impact of the Oklo plant is optimized and the negative environmental impact of the Oklo site on the resources in the vicinity and region is minimal, its contribution to the cumulative negative impact on those resources due to past, present and reasonably foreseeable future actions in the vicinity and region is also expected to be negligible. The cumulative environmental impact of the Oklo plant on a region is expected to be strongly positive due to avoided emissions and the very low lifecycle carbon footprint. The contribution of other actions will not be addressed here in this generic review of environmental impact. As more information is provided for the cumulative impacts for specific sites, this information will likely be presented together with site-related information in the preceding sections of this environmental report.

4 PROJECT JUSTIFICATION

Oklo has identified potential microgrid customers in Alaska, islands, and other high power cost areas of the U.S. as well as communities interested in lowering their carbon footprint. These markets share the common challenges of high electricity prices and reliability concerns with their current electricity sources. Oklo has performed a detailed cost analysis on the plant design and shown that it can provide a competitive product in most of these remote markets, reducing electricity costs by over 70%. Additionally, the Oklo reactor is projected to boost capacity factors by as much as 80%, as most of these locations currently rely on electricity generated by diesel generators. An additional benefit for remote markets is the capability for Oklo reactors to cogenerate heat for district heating. Where district heating is impractical, the affordable electricity rates enabled by Oklo reactors will allow some customers to switch to electric heating and reduce reliance on fuel oil. The Oklo reactor offers a solution that is carbon-free and can replace up to a million metric tons of CO_2 per diesel generator replaced.

In addition to these off-grid customers, many industrial customers connected to the traditional electric grid also desire enhanced reliability through an always-on, locally-sourced energy alternative. These customers include data centers, industrial sites, and power plants. For example, reliability of electricity for data center users and owners is a major concern, as the world relies more and more every day on these facilities to function 24/7. Another example is the need for a reliable backup power source for large, grid-connected, industrial sites and power plants, in the event of a partial disruption or total outage of the electrical grid. And in many locations within the U.S., the grid is either expensive or unreliable such that a separate source of power is desirable.

In most cases Oklo reactors will be serving a microgrid with well-defined power supply and demand. As a result, the "Need for Power" analysis will be straightforward compared to projects that serve larger grids or multiple regions. Whether these microgrids are remote or simply islanded from the main grid, the available energy alternatives that meet the purpose and need for the Oklo reactor will generally be limited to diesel generators. This is a direct result of both the design of the Oklo reactor and the business strategy of the company, reaching markets that have a particular need that currently can only be met by diesel generators. As a result, the typical alternatives analysis will also be quite straightforward, focused primarily on the environmental benefits of the Oklo reactor in comparison to diesel generators.

OKLO

V. Addressing Loss of Large Area of Plant Due to Explosions or Fire

1 PURPOSE AND SCOPE

Title 10 to the Code of Federal Regulations (10 CFR) Section 52.80 requires applicants to meet requirements as far as loss of large areas of the plant due to explosions or fire. Section 52.80(d) to 10 CFR specifies:

> A description and plans for implementation of the guidance and strategies intended to maintain or restore core cooling, containment, and spent fuel pool cooling capabilities under the circumstances associated with the loss of large areas of the plant due to explosions or fire as required by § 50.54(hh)(2) of this chapter.

Oklo is not piloting this section.

OKLO

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