Design Overview

April 9, 2019

NRC Headquarters

Meeting outline

- 9:00 am – 9:15 am | Introductions
- 9:15 am – 9:45 am | Introduction to Oklo
- 9:45 am – 10:30 am | Design dive
- 10:30 am – 10:40 am | Break
- 10:40 am – 11:20 am | Pilot and safety case
- 11:20 am – 12:00 pm | Looking forward and conclusion

Introduction to Oklo

9:15 am - 9:45 am

Introduction to Oklo

- Founded in 2013
- Awards
- Funded in 2015, additional funding in 2018
- Growing team
- Not focused on press
- Designing compact fast reactor – microreactor

Need for small-scale nuclear

- Many remote areas currently employ diesel generators for electricity production, which are expensive, unreliable, and dirty
- In Alaska, over 200 microgrids bring power to rural residents
  - Alaskan residential electricity rates average more than 50 cents/kWh
  - 400 million kWh from diesel in Alaska statewide in 2013, costing $200M/yr
- Other isolated areas (e.g. islands) also spend significantly on electricity generation
  - US Virgin Islands spend about $240M/yr
- NRC stated priority for applications for high cost markets (CFR 50.43(b))

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Oklo solution – passive compact fast reactor

- MW-scale fast reactor meets the needs of these communities
- Can generate electricity and process heat
- Well-understood fuel and materials
- No moving parts in primary cooling system
- Reduced maintenance profile
- No offsite power dependence
- No carbon emissions

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Reactor emplacement

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Power conversion

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Security by Design

- located below-grade/layered within robust reactor module
- Metal fuel form is robust
- Operate at high temperature and fast spectrum for self protection
- Strong negative temperature/power feedback

Oklo NRC interactions

- Drop-ins since 2013
- Paid interactions since 2016
- Highlights:
  - Ongoing licensing project planning
  - Oklo core design report
  - Oklo risk analysis and source term report
  - Metal fuel database report
  - Interactions on QAPD, Principal Design Criteria, and application structure
  - DG-1353 pilot application
  - SGI handling plan
- Working towards COLA in late 2019

Pre-Application Activities - Oklo

Who:	OKLO Inc.
What:	Pre-application interaction to discuss issues related to the OKLO design (Docket Number 99902046)
When:	Pre-application interactions began in November 2016.
Website:	https://oklo.com/

Project Overview

The staff of the U.S. Nuclear Regulatory Commission (NRC) engaged in pre-application activities with Oklo Inc. starting in November 2016. Oklo, Inc. is a Silicon Valley based company that is developing a compact fast reactor which uses liquid metal heat transport.

For additional information, please use the Advanced Web Search feature of our Agencywide Documents Access and Management System (ADAMS) search on docket number 99902046 to view OKLO pre-application documents.

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Design Dive

9:45 am - 10:30 am

[redacted]

Key design features

- **Size and source term:** Sized like non-power reactor, not like average power reactor
- **Fuel and materials:** Fuel, spectrum, and materials look like EBR-II fuel, spectrum and materials
- **[redacted] and burnup:** [redacted] and very low burnup
- [redacted]

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Size and source term

- The Oklo reactor power is on the order of magnitude of a non-power reactor
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- No large volumes of activated liquids or radwaste

Fuel and materials

- The Oklo reactor utilizes fuel and materials with a wealth of testing data from the Integrated Fast Reactor (IFR) program
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-
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- Strong negative reactivity feedback

Metal fuel

- Keeps fission products within the metal up to a certain burnup
- Resistant to cracking or chipping - does not pulverize
- Relative ease of manufacture, insensitivity to manufacture method
- High thermal conductivity and low specific heat
  - Lower peak fuel temperature and stored energy
  - Easier to dissipate heat from the fuel
- Large negative temperature reactivity coefficient
  - Metal fuel expands due to temperature increases

EBR-II

- EBR-II was a 62.5MWth, 19 MWe sodium-cooled fast reactor with metallic fuel
- EBR-II:
  - operated for 30 years
  - sold power to the grid
  - had higher capacity factor than fleet at the time
- Years of quality assured testing done with the EBR-II reactor

EBR-II Shutdown Heat Removal Tests (SHRT)

- Performed on the same day (April 3rd, 1986)
- Two types of unprotected loss-of-cooling accidents
  - Loss of Flow Without Scram
  - Loss of Heat Sink Without Scram
- Performed on the actual, operating reactor at full power
- Started back up after both tests without damage

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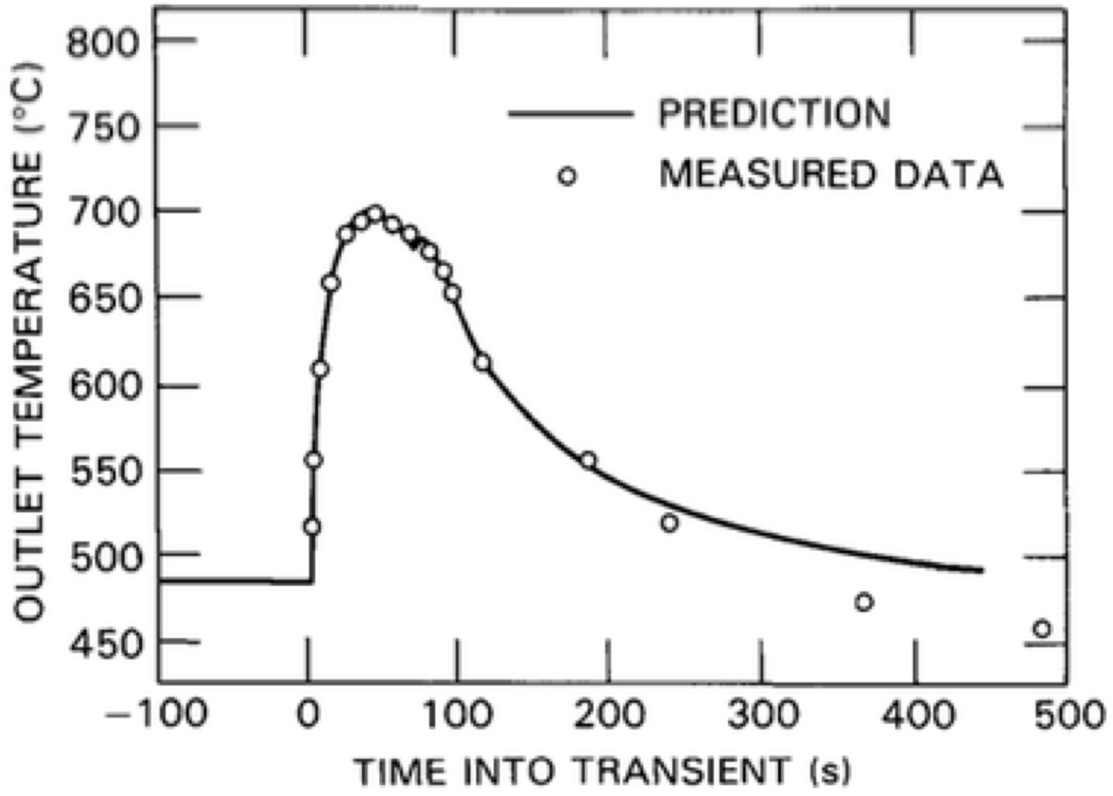
EBR-II Loss of Flow Without Scram

- Loss of Flow Without Scram (LOFWS): Primary coolant pumps turned off while operating at full power
- Reactor shut down due to fuel thermal expansion feedbacks
- No damage to fuel or otherwise



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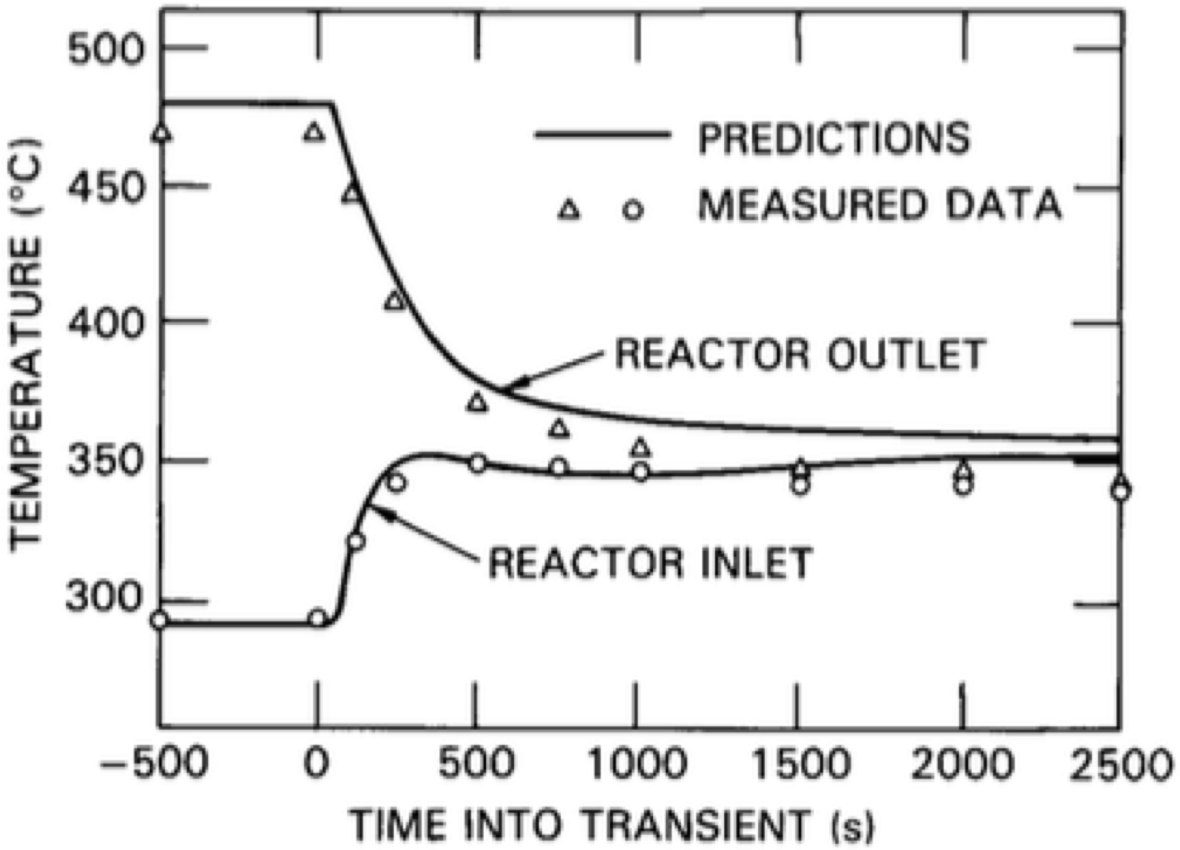
EBR-II Loss of Heat Sink Without Scram

- Loss of Heat Sink Without Scram (LOHSWS): Intermediate coolant pumps turned off while operating at full power
- Again, reactor shuts down without scram due to thermal expansion feedbacks
- No damage to fuel or otherwise



EBR-II Safety Test Takeaways

"These are sensational results. Two of the most severe accidents that can threaten nuclear power systems have been shown to be of no consequence to safety or even operation of EBR-II. The reactor was inherently protected without requiring emergency power, safety systems, or operator intervention."

-J.I. Sackett

"OPERATING AND TEST EXPERIENCE WITH EBR-II, THE IFR PROTOTYPE", Progress in Nuclear Energy 31, 1-2, pp. 111-129, 1997.

and burnup

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- Very low burnup
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  - Low burnup means well characterized regarding fuel swelling and other materials issues that increase with burnup
  - Low burnup also means very few fission gasses created in the fuel – small source term

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Design parameter comparison

	EBR-II	PRISM	PWR	Oklo
Reactor type	SFR	SFR	PWR	Compact fast reactor
Operating power ***[MWth]***	63	840	3400	
Fuel inventory ***[tHM]***	0.3	26	90	
Average discharge fuel burnup ***[MWD/kgHM]***	94	96	33	
Core volume-averaged power density ***[kW/L]***	942	240	104	
Fuel mass-averaged power density ***[kW/kg]***	171	29	38	

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Modeling

- High fidelity modeling and simulation of reactor core and core cooling possible due to small size and modern methods
- Utilize monte carlo codes as primary neutronic analysis
  - These are usually used to benchmark other codes because computationally expensive, but can be used as primary analysis for the Oklo reactor because it is small, simple, fast spectrum and tightly coupled
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Simple structures, systems, and components

- No pumps, valves, etc. in core or primary heat transport from core
- Passive and very efficient heat transport from core – heat pipes function as thermal superconductors
- Hundreds of independent paths for passive heat transport from core
- No chemistry control required
- No pressure control required
- Minimal safety-related SSCs expected

Other design features

- Below-grade emplacement offers simplicity and safety benefits
  - Seismic
  - Aircraft impact
  - Tornado/high wind
  - Terrorist threat analysis
  - Etc
- Primary heat transport operates at sub-atmospheric pressure
  - No significant driving forces for release

No offsite power dependence

- Driven by market needs – may be the only source of power
- Thus, designed without reliance on offsite power
  - LOOP and SBO not a concern
- Very little decay heat – no active systems required
  - 1000x less than LWR
  - On the scale of a lawn mower engine
- Backup sources of power still being evaluated, not needed for safety

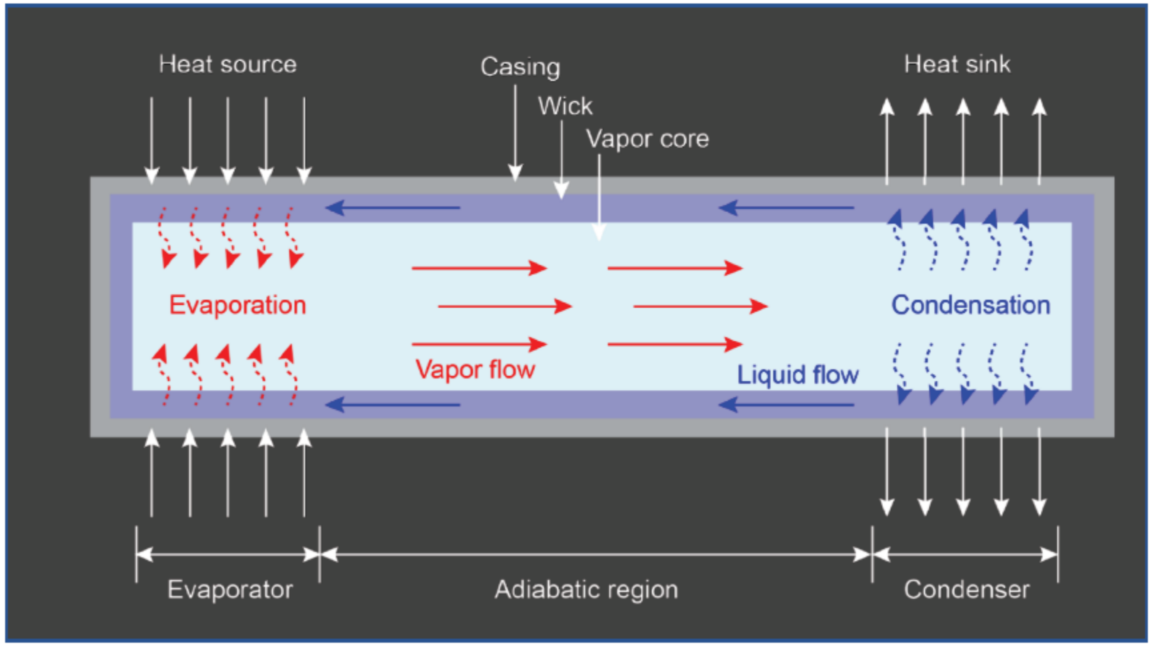
Protected fissile material

- No refueling onsite
- No spent/fresh fuel stored onsite, fissile material only present in core
- Reactor placement underground
- Special machinery required for maintenance
- Heavy components that both shield core and make access difficult

Reactor cutaway view

- Heat is generated in the active core
- Heat moves to heat pipes via conduction
- Transferred to heat exchanger units
- Heat exits reactor module to secondary side

Heat pipe operation



- No chemistry control
- No filtering
- No makeup inventory required
- No pressure maintenance required, operates at sub-atmospheric pressure
- No possibility for flow or temperature instabilities as in complex flow loops
- Self annealing in case of exposure to air (extremely low likelihood event)
- Long life data
- Irradiation data from EBR-II

Core design

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- Redundant “reactor cells” heat pipe
- Heat pipes passively transfer heat to secondary side
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Reactor cell axial view

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  "reactor cell
- Heat pipe
- Heat moves from fuel to heat pipe via conduction
- Reactor cells comprised of
  , fuel, gas plenum

Reactor cell cross-sectional view

- Redundant reactor cells, cooling mechanism (heat pipe)
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- Well-understood materials
- Comprised of , fuel, heat pipe, and

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Site footprint

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Break

10:30 am - 10:40 am

Pilot and Safety Case

10:40 am - 11:30 am

Oklo DG-1353 pilot application overview

- NRC has been developing guidance to support a risk-informed structure (DG-1353) and called for non-LWR developers to pilot the guidance
- DG-1353 references NEI 18-04, "Risk-Informed Performance-Based Guidance for Non-Light Water Reactors Licensing Basis Development"
- Oklo piloted the DG-1353 guidance holistically in an application structure (ML18282A002)

Oklo DG-1353 pilot application results

- Scope of pilot was to internal, at-power events
  - However, aircraft impact analysis was included
  - Included security plan as well as environmental report, among other sections
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Oklo DG-1353 pilot application structure based on regulatory requirements

10 CFR 52.77, 52.79, and 52.80 specify application requirements for a COLA. These can be grouped into the following 5 sections:

I. Company Information and Financial Requirements (52.77)

II. FSAR (52.79)

III. Proposed ITAAC – not piloted (52.80)

IV. Environmental Report (52.80)

V. Addressing Loss of Large Area of Plant Due to Explosions or Fire – not piloted (52.80)

The final application is expected to have seven (7) sections. Two (2) other high-level parts are expected to be added to this structure or separated out from the FSAR requirements section to mimic past application structures:

VI. Technical Specifications (which will largely refer to the FSAR Section 23), and

VII. Departures/Exemptions.

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Oklo DG-1353 pilot application contents – Part I

- Company Information and Financial Requirements to satisfy 50.33 as specified in 52.77
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- Three GAIN vouchers, totaling over $1M
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- Class 103 combined license, custom COL – Part 30, Part 40, Part 70 licenses timelines in future

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Oklo DG-1353 pilot application contents – Part I continued

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Oklo DG-1353 pilot application contents – Part II – FSAR

1. Siting Information
2. Description and Analysis of Structures, Systems, and Components
3. Radioactive Materials to Be Produced in Operation
4. Probabilistic Risk Assessment
5. Design and Performance of Structures, Systems, and Components
6. Design of Facility
7. Fire Protection
8. Station Blackout
9. Electrical Equipment Important to Safety
10. Programs Related to ASME Codes
11. Reactor Vessel Maintenance Program
12. Maintenance Rule
13. Earthquake Criteria
14. Unresolved and Generic Safety Issues
15. Emergency Plans
16. Emergency Planning with State and Local Governments
17. Prototype Operational Conditions
18. Design and Construction Quality Assurance Program Description
19. Organization Structure for Operations
20. Operational Elements of the Quality Assurance Program Description
21. Preoperational Testing and Initial Operations
22. Operational Plans
23. Technical Specifications
24. Technical Qualifications of the Applicant
25. Operator Training Program
26. Training Program
27. Operator Requalification
28. Physical Security
29. Safeguards
30. Incorporation of Operational Insights
31. Radiation Protection
32. Fire Protection Program
33. Risk Reduction from Anticipated Transients Without Scram
34. Criticality Accidents
35. Fitness for Duty Program
36. Minimization of Contamination
37. Aircraft Impact Assessment

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Oklo DG-1353 pilot application contents – Part IV – Environmental Report

- Because of the small size of the Oklo reactor, the safety and environmental case does not depend on small or in some cases even large variations in sites
  - May include parameters like seismic activity, water level, flooding, surrounding population evaluations, etc. – should not require the level of data required for large LWRs where a much smaller change could mean a large safety or environmental impact
- Historical standards for data needed for large LWRs may not apply
  - For example, multi-year measurements of wind speed measurements are not required for calculating dose if our analysis already assumes worst case wind speeds.
  - For another example, it would be expected that much less information is needed compared with large LWRs on nearby water resources since the reactor and site requires no water.

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Core Concept of Safety Case

- Small reactor
- Small source term
- Small risk to public health and safety and the environment
- Regulatory limits can be met by inherent, physical characteristics as opposed to active or passive systems

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Consistent Results

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Release Pathways

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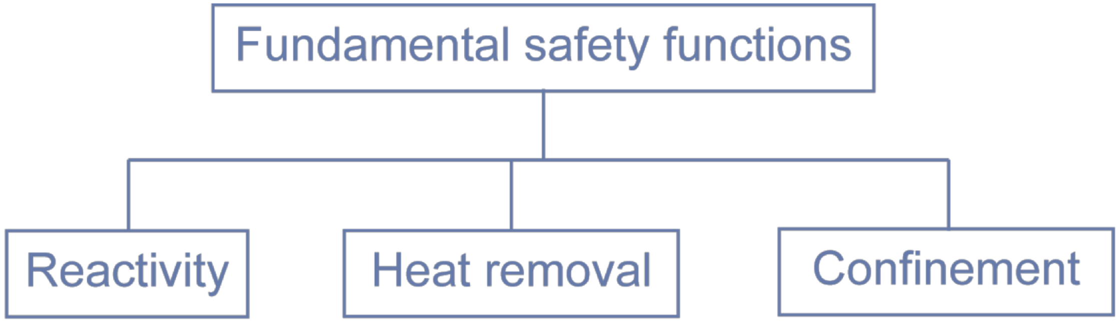
Fundamental Safety Functions



- Typically referenced from IAEA Specific Safety Requirements SSR-2/1, “Safety of Nuclear Power Plants: Design”
- Also included in NRC non-LWR Roadmap (ML17312B567)

1. Control of reactivity
2. Removal of heat from the reactor and fuel store
3. Confinement of radioactive material

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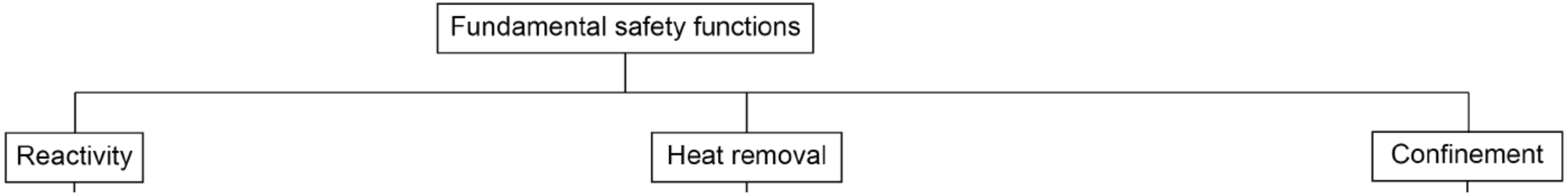
Fundamental safety functions
Reactivity
Heat removal
Confinement

Required Safety Functions

<u>Reactivity:</u>
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<u>Heat Removal:</u>
-

<u>Confinement:</u>
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Looking Forward and Conclusion

11:20 am - 12:00 pm

Looking forward:

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Role of the other agencies

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Looking forward: application

- Oklo is working with a number of partners towards completing analysis not covered in the pilot application including:
  - Seismic analysis for sites
  - Fire protection analysis
  - Near-field dosing analysis
  - Completing security planning
  - Completing quality assurance procedures
  - Data qualification

Questions?