Safety case, radiation protection, automatic controls

August 22, 2019

NRC Headquarters

Outline for public meeting

- Introduction to Oklo
- Introduction to the Oklo design
- Safety case, radiation protection, automatic instrumentation and controls

Introduction to Oklo

Introduction to Oklo

- Founded in 2013
- Awards – MIT 100k, MIT Clean Energy, MassChallenge, YCombinator
- Funded in 2015, additional funding in 2018
- Oklo awarded the most GAIN vouchers of any company
- Developing compact fast reactor – advanced fission battery as part of a microgrid clean energy plant

Market need

- 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))

OKLO

Oklo solution – advanced fission battery

- MW-scale to meet the needs of these communities
- Well-understood fuel and materials
- No moving parts in primary heat transport
- Reduced maintenance profile
- No offsite power dependence
- No emissions

OKLO

Introduction to the Oklo Design

Oklo design - 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, key properties insensitive 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
- Designed to have very low power density
- Utilize data from the IFR program, particularly EBR-II experimental data

Fuel - 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

OKLO

Fuel - 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

OKLO

Fuel - 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.

Simple structures, systems, and components (SSCs)

- 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
- On the order of one hundred 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

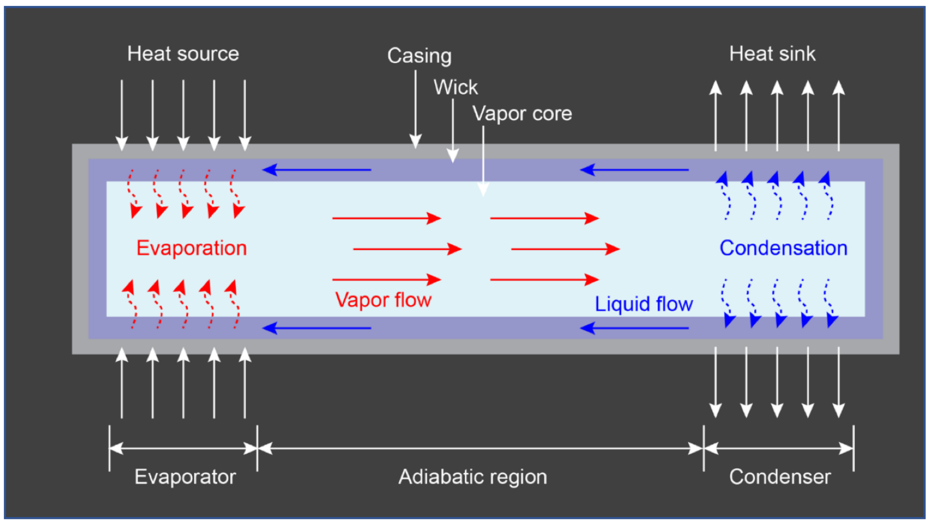
- Below-grade emplacement of the entire system offers simplicity, safety, and security benefits, such as:
  - Seismic
  - Aircraft impact
  - Tornado/high wind
  - Terrorist threat analysis
- Primary heat transport operates at sub-atmospheric pressure

  No significant driving forces for release
- No periodic refueling intervals
  - Little to no fuel movement
  - Likely no heavy machinery onsite – no way of removing fuel

No offsite power dependence

- Driven by market needs – may be the only source of power
- Thus, designed without reliance on AC power
  - Loss of offsite power (LOOP) and station blackout (SBO) not a concern
- Very little decay heat – no active systems required
  - 1000x less than LWR
  - On the scale of a lawn mower engine within ~12 hours
- Backup sources of power still being evaluated, not needed for safety

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
- Long life data
- Irradiation data from EBR-II

OKLO

Safety Case

Core concept of safety case

- Small reactor – smaller heat output than even the MIT research reactor, decay heat at ~12h after shutdown on order of lawnmower
- Small source term – small, low-enriched fuel inventory + few physically possible ways to mobilize, very low burnup
- Lower power density than even the NGNP reactor case

Goal:

- Power with minimal risk to public health and safety and the environment
- Regulatory limits can be met by inherent, physical characteristics as opposed to active or even passive systems

Consistent results

- Multiple paths analyzed to date:
  - Initial risk analysis – no core damage
  - Deterministic source term/analysis of core melt – analysis of core melt led to dose well below 50.34 limits at 100m
  - Risk-informed analysis – DG-1353 pilot:
    - All risk-informed design basis events resulted in no dose to the public
    - Only one deterministic design basis accident resulted in dose, which was well below the 50.34 limits at 100m from the reactor
  - Fundamental Safety Functions (FSF) analysis showed that all FSF met by inherent features
- Goal is to meet longstanding regulatory priority of safety for maximum credible accident (10 CFR 100.11) demonstrating safety through worst case single failure criterion

(*Controlling the Atom: The Beginnings of Nuclear Regulation 1946-1962*, George T. Mazuzan and J. Samuel Walker, University of California Press, 1984, page 228. This book was later published by NRC as NUREG-1610)

OKLO

Maximum credible accident

- One maximum credible accident aligns with deterministic design basis accident previously analyzed through the pilot of DG-1353
  - Oklo reactor demonstrated a dose of an order of magnitude below regulatory limits at 100m
- Reliance on deterministic analysis removes uncertainties introduced through reliance on risk analysis for a FOAK reactor, while Oklo can still show thorough analysis and learnings from advanced probabilistic risk analysis
- Further precedent for safety case and EPZ/site boundary for reactors of this size regulated by the NRC is shown through existing non-power reactors

Radiation Protection

Introduction to radiation protection

- Purpose: to ensure effective monitoring and control of internal and external doses, keeping radiation exposure as low as reasonably achievable (ALARA)
- Goal is to comply with 10 CFR 20
- Plant designed with radiation protection in mind. The benefit of having decades of lessons learned experience

OKLO

Radiation sources

- All possible sources are contained
  - Effluents : Contained or adequately shielded to prevent activation
  - No spent fuel on site
  - Nearly everything in the plant is a structure, ensuring easy control of waste and byproducts
- Source terms are small
  - Even in worse case scenarios, the source term is below the regulatory limits
    - Fission product inventory
    - Effluent concentrations

OKLO

Shielding utilization

- Biggest contributor to radiation protection
- Used to minimize onsite and offsite radiation exposure
- Built into design
  - Incorporated industry lessons learned
- Using shielding materials that are proven and predictable
  - Mitigate secondary gamma radiation
  - Strong resilience to radiation damage

No radiation areas

- Plant layout allows for normal operations without access to radiation areas
  - No RCA
  - No reactor access
- Remote monitoring of radiation instrumentation possible

OKLO

Automatic Instrumentation and Controls (I&C)

Overview of I&C

- Redundant, diverse, and independent instrumentation including:
  - Core conditions
    - Flux sensors covering full range of reactor power
    - Temperature sensors
  - Power conversion system
- No human capability to increase core power in operation
- No safety implications of controls

OKLO

DG-1353 pilot description of I&C

- Oklo provided a high-level description of I&C systems
- All I&C systems fully automatic
- Purpose of I&C systems is to monitor and control performance of the plant:
  - Reactor trip system
    - Initiates actions necessary for a reactor trip
  - Plant control system
    - Controls power conversion system
  - Monitoring system
    - Monitors plant-wide parameters
  - Information display system

OKLO

I&C in regulatory review

- Provide analysis on safety goals of I&C systems
  - Show analyses that spurious actuation bounded by safety case
- High-level system description
  - Provide adequate structures, system, and components descriptions for the I&C system to enable regulatory review

Questions