#### A Thesis

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Degree of Master of Science

with a

Major in Nuclear Engineering

in the

College of Graduate Studies

University of Idaho

by

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Department Administrator: Indrajit Charit, Ph.D.

#### Abstract

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### ACKNOWLEDGEMENTS

This work and my coursework was completed under a Graduate Fellowship funded by Nuclear Regulatory Commission (NRC). I would like to thank Dr. McKellar...

### DEDICATION

To my mother, Tammy, who planted and nurtured my love of science. To my father, Paul, who taught me how to design and build, and showed me that I am an engineer. To my cats, Babe and Bunyan, who stayed up with me all those late nights studying and writing. Thank you for your endless support.

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1	Hello!	Ć
2	F strings	Ć

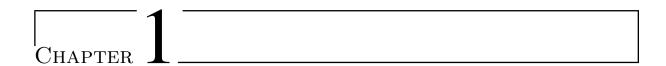
### ACRONYMS

LWR Light Water Reactor.

 $\mathbf{MSNB}\,$  Molten Salt Nuclear Battery.

 ${\bf NRC}\,$  Nuclear Regulatory Commission.

**PID** Proportional-Integral-Derivative.



### Introduction

#### 1.1 Background

The Molten Salt Nuclear Battery (MSNB) is a self contained design for a liquid fueled molten salt microreactor [1, 2]. It is fueled by an inorganic form of uranium,  $UF_4$ , dissolved in a coolant salt such as FLiNaK (a eutectic mixture of three alkali fluorides) or FLiBe (a mixture of LiF and  $BeF_2$ ) [3]. Heat is generated in the core by fission, is transported by the natural circulation of the coolant/fuel salt, and rejected to a secondary working fluid in an integrated heat exchanger. Criticality is manipulated using axial control drums, which may be rotated to aim either a neutron reflecting material or a neutron absorbing material towards the core.

#### MICRO REACTORS

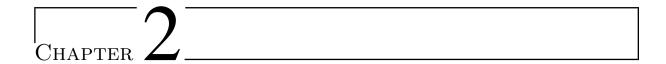
Its like a reactor but smol. This is a test from CAES.

#### Molten Salt Reactors

Light Water Reactor (LWR)

#### 1.2 Scope

As a developing design, work has been done on neutronics [2], thermal-hydraulics and autonomous load following [1], and corrosion concerns [4]. However, until now, little to no work has been done on the control system. First and foremost, this work details a multiphysics characterization of the MSNB required to design a feedback controller capable of matching the core power generation to the secondary power demand. In addition to the main control mode of following power transients during normal operation, specific discussion is centered around more dynamic time periods, namely: 1) initial start-up; 2) shutdown, both planned and emergency; and 3) restart;



### PROCESS CONTROL ENGINEERING

#### 2.1 Feedback

#### 2.2 Feedforward

The term 'Feedforward' can be used to refer to any element in the control block diagram that exists outside of the feedback loop.

#### DISTURBANCE FEEDFORWARD

Not that useful since disturbance transport delay is on the order of minutes and disturbance dynamics are on the order of milliseconds

#### PRE-FILTER

This could be electronic (less ideal) or physically realized by decoupling

#### 2.3 TIME VARIANCE

Fissile depletion - time function parameters or look-up table to gain-schedule and turn the time variant system into a shift invariant system.

In addition to the relatively slow time variance of fissile fuel depletion during steady-state critical operation, there are specific times in a MSNB's expected operational life-cycle that exhibit a higher degree of time variance: 1. Start-up; 2. Shut-down; and 3. Re-start.

#### START-UP

Black-start may need to deal with thawing salt - main concern is fission product neutron poison build-up (discuss the burnable poison stuff)

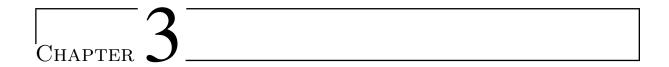
#### Shut-down

Planned shut-down

Emergency Shutdown/SCRAM(must be passive) Decay heat and keeping the salt liquid for restart

Re-start

 $^{135}Xe$  stripper



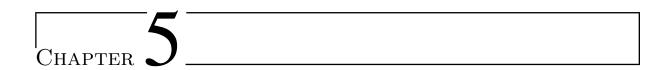
## REACTOR CHARACTERIZATION

- 3.1 Reactor Design Selection
- 3.2 Neutronics Modeling
- 3.3 Process Simulation

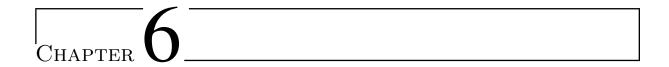


## Controller Design

- 4.1 REACTOR TRANSFER FUNCTION
- 4.2 Tuning Methodology



## Results and Analysis

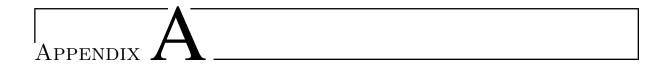


## Conclusions

- 6.1 Limitations
- 6.2 Future Work
- 6.3 Summary Remarks

### REFERENCES

- [1] Carter, John P., 2022. Multi-Physics Investigation of a Natural Circulation Molten Salt Micro-Reactor that Utilizes an Experimental In-pile Device to Improve Core Physics and System Thermal-Hydraulic Performance. Ph.D. thesis, University of Idaho.
- [2] Peterson, John, 2019 8. An Analysis of the Nuclear Characteristics of a Molten Salt Microreactor. Master's thesis, University of Idaho.
- [3] Roper, Robin V., Sabharwall, Piyush, Christensen, Richard, 2019. Chemical overview of molten salts.
   ANS Annual Meeting.
   URL https://www.ans.org/pubs/transactions/article-45524/
- [4] Roper, Robin, 2022. The Effect of Impurities and Geometry on the Corrosion and Thermodynamic Behavior of Molten Salts. Ph.D. thesis, University of Idaho.



## Test

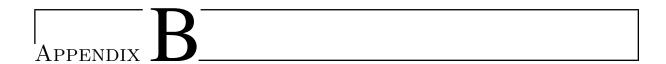
Code 1: Hello!

```
print("Hello World") #comment
try:
    a=2/x
except ZeroDivisionError:
print('undefined')
```

Inline codes like import numpy

Code 2: F strings

```
1  x = 4
2  print(f"The numeral four: {x}")
3  #comment
```



# What

Straight Cash Homie