A Thesis

Presented in Partial Fulfillment of the Requirements for the

Degree of Master of Science

with a

Major in Nuclear Engineering

in the

College of Graduate Studies

University of Idaho

by

Sam J. Root

Major Professor: Michael McKellar, Ph.D.
Committee Members: Dakota Roberson, Ph.D.; Robert A. Borrelli, Ph.D.
Department Administrator: Indrajit Charit, Ph.D.

Abstract

Lorem ipsum dolor sit amet, consectetuer adipiscing elit. Ut purus elit, vestibulum ut, placerat ac, adipiscing vitae, felis. Curabitur dictum gravida mauris. Nam arcu libero, nonummy eget, consectetuer id, vulputate a, magna. Donec vehicula augue eu neque. Pellentesque habitant morbi tristique senectus et netus et malesuada fames ac turpis egestas. Mauris ut leo. Cras viverra metus rhoncus sem. Nulla et lectus vestibulum urna fringilla ultrices. Phasellus eu tellus sit amet tortor gravida placerat. Integer sapien est, iaculis in, pretium quis, viverra ac, nunc. Praesent eget sem vel leo ultrices bibendum. Aenean faucibus. Morbi dolor nulla, malesuada eu, pulvinar at, mollis ac, nulla. Curabitur auctor semper nulla. Donec varius orci eget risus. Duis nibh mi, congue eu, accumsan eleifend, sagittis quis, diam. Duis eget orci sit amet orci dignissim rutrum.

Nam dui ligula, fringilla a, euismod sodales, sollicitudin vel, wisi. Morbi auctor lorem non justo. Nam lacus libero, pretium at, lobortis vitae, ultricies et, tellus. Donec aliquet, tortor sed accumsan bibendum, erat ligula aliquet magna, vitae ornare odio metus a mi. Morbi ac orci et nisl hendrerit mollis. Suspendisse ut massa. Cras nec ante. Pellentesque a nulla. Cum sociis natoque penatibus et magnis dis parturient montes, nascetur ridiculus mus. Aliquam tincidunt urna. Nulla ullamcorper vestibulum turpis. Pellentesque cursus luctus mauris.

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.

Table of Contents

Abstract	ii
Acknowledgements	iii
Dedication	iv
Table of Contents	. v
List of Tables	vii
List of Figures	. viii
List of Codes	. ix
List of Acronyms	Х
Chapter 1: Introduction	1
Background	1
Scope	. 1
Chapter 2: Process Control Engineering	. 2
FEEDBACK	. 2
Feedforward	2
Time Variance	2
Chapter 3: Reactor Characterization	4
REACTOR DESIGN SELECTION	4
Neutronics Modeling	. 4
Process Simulation	. 4
Chapter 4: Controller Design	. 5
REACTOR TRANSFER FUNCTION	5
Tuning Methodology	. 5
Chapter 5: Results and Analysis	. 6
Chapter 6: Conclusions	. 7
Limitations	7
Future Work	. 7
Communication Description	_

References																			8
Chapter A: Test .																			ç
CHAPTER B: WHAT			 																10

LIST OF TABLES

LIST OF FIGURES

LIST OF CODES

1	Hello!	Ć
2	F strings	Ć

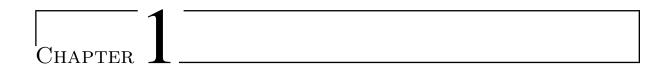
ACRONYMS

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 [1, 2]...

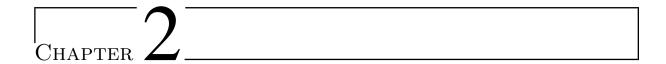
MICRO REACTORS

MOLTEN SALT REACTORS

Light Water Reactor (LWR)

1.2 Scope

Until now, little to no work has been done on the control system...



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)

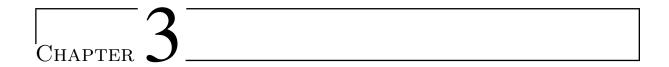
Shut-down

Planned shut-down

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

Re-start

 ^{135}Xe stripper



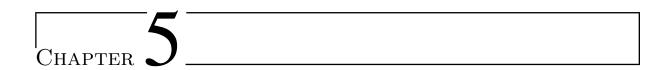
REACTOR CHARACTERIZATION

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

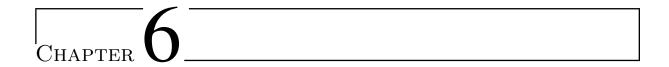


Controller Design

- 4.1 REACTOR TRANSFER FUNCTION
- 4.2 Tuning Methodology



Results and Analysis

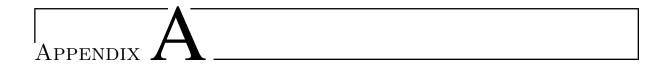


Conclusions

- 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.



Test

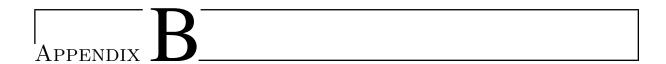
Code 1: Hello!

```
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