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AMBIDEXTER Dynamics and Self-Regulation Capability

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1. Introduction

Safety-related events in a nuclear reactor system are mostly incurred by sudden imbalance between their heat source and sink behaviors. Controllability and resiliency are assessed if the system be safely recoverable from the imbalance. Inherent safety characteristics of the reactor should be an ideal design philosophy in this aspect.

The AMBIDEXTER [1] safety design was explored with maximum reliance on counteractive responses by the system itself. As for the realization, negative reactivity feedback and fail-safe criteria are the fundamental considerations. Details of how to implement them in the design can be found in the paper accompanied.[1]

As shown in Figure 1, the reactor and the primary heat exchanger are integrated into a closed loop in the vessel. The fuel salt flows downwardly in the outer core region, gains fission heat and then, rises upwardly through the central inner core region where resonance absorbers face better conversion chance. In the primary heat exchanger, heat transfer between the tube-side fuel salt and the shell-side coolant salt is made. For chemical processing, part of the fuel salt flow is discharged from the heat exchanger and returns to the reactor through bypass line.

This paper examines the dynamic performances of the AMBIDEXTER reactor system to investigate the range of its self-regulation capability and safety impacts.

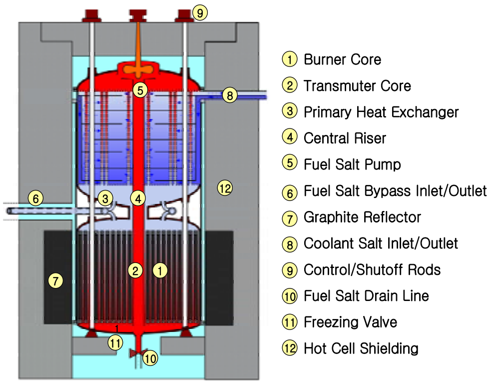

Fig 1. AMBIDEXTER Integral Reactor System

2. AMBIDEXTER Dynamics

2.1 AMBIDEXTER Neutron Kinetics

Major differences in neutron kinetics between the solid fuel reactors and the AMBIDEXTER are due to the flow- and temperature-induced distribution changes of the nuclide densities in the core.

For steady operations, the sweep-out of the delayed-neutron precursors with fuel flow reduces the fractions of delayed-neutron yields to almost one half of their dire generation levels.

2.2 Inherent Safety Features

The AMBIDEXTER is likely a critical assembly, as continuous supply of fissile by on-line feeding keeps the reactor critical for steady operation with the rated power. Maximum excess reactivity at any circumstances should be much less than the prompt criticality criteria.

As another advantage of the liquid fuel, the reactivity coefficient of fuel salt temperature is significantly high compared to that of the solid fuel reactors, mainly due to its larger thermal expansion and subsequently less in-core inventory. Should the graphite moderator be doped with a specific burnable poison material, enhancement in negative power coefficient is guaranteed.

And the freezing valve mounted on the fuel salt drain line close to the reactor bottom automatically opens at a loss of electrical power and forces the fuel dumping by the gravity, which guarantees immediate sub-criticality of the reactor.

Most of all, the credible amount of releasable radio-nuclides at accidents should be much less than that from the conventional solid fuel reactors, because of online reconditioning continuously.

2.3 MATLAB/Simulink System Model

For dynamics analysis, the reactor and linked energy transport and conversion systems were modeled using the MATLAB/ Simulink. Figure 2 shows the simplified diagram of the system model.

The neutron kinectics model was based on 6-delayed neutron group equations and modified to include in-core, by-pass and recirculation flow effects. The reactivity feedback was accounted for both fuel and moderator temperature changes. And as for transient initiators, fuel and coolant flow changes as well as various reactivity insertion modes could be inputted.

Multi-lump models for heat generation and transport in the serially coupled inner and outer cores, for heat transports in the reactor system, cross the intermediate loop and in the devices were incorporated.

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[1] Advanced Molten-salt Break-even Inherently-safe Dual-missioning and EXcellenTly-Econogical Reactor

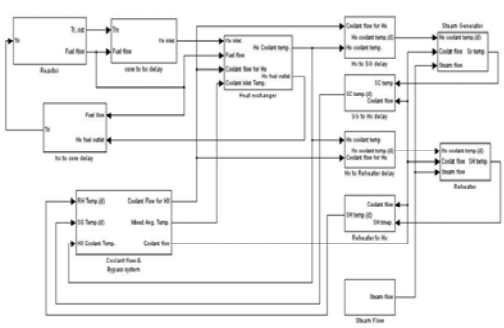

Fig. 2 Simulation Model for the AMBIDEXTEWR Dynamics

Key design characteristic parameters of the 250MW$_{th}$ AMBIDEXTER, used for system transient simulations are summarized in Table 1.

Table 1: Input Parameters for Dynamics Simulations of the 250MW$_{th}$ AMBIDETER

Parameters	Values
- Reactor power, MW$_{th}$	250
Fuel salt/graphite	230.7/19.3
- Delayed neutrons:	β_i λ_i
Group 1	$7.31\text{x}10^{-5}$, 0.0125
Group 2	$7.44\text{x}10^{-4}$, 0.0289
Group 3	$3.83\text{x}10^{-4}$, 0.0920
Group 4	$1.12\text{x}10^{-3}$, 0.2680
Group 5	$5.05\text{x}10^{-4}$, 0.7090
Group 6	$2.10\text{x}10^{-4}$, 2.6300
- Prompt neutron lifetime, s	$1.41423\text{x}10^{-4}$
- Reactivity coefficients, pcm/℃	
Fuel salt	-1.4
Graphite	1.2
- Nominal inlet/outlet temperature, ℃	
Reactor	565.6/704.4
Intermediate heat exchanger	454.4/565.6
- Nominal mass flow rates, kg/s	
Fuel salt	1,537
Coolant salt	1,494

2.4 Simulations for Transient without Trip Scenarios

In order to investigate the self-regulation capability of the AMBIDEXTER design, various accident scenarios and anticipated operational occurrences were simulated.

Table 2 summarizes some results for scenarios of fuel or coolant salt flow reduction with 10%/s rate in unison. And Figure 3 draws cases of the reactivity insertion with different rates in a second.

Table 2: Summary of Transient-without-Trip Simulations

	Power(MW)		Fuel T(℃)		Coolant T(℃)	
	Max.	Sat.	Max.	Sat.	Max.	Sat.
-Fuel flow 50% reduction	152.71	157.83	734.71	734.71	565.35	493.23
-Coolant flow:						
Bypass 10%	249.48	244.50	708.33	708.33	571.68	571.68
25%	249.48	235.14	714.99	714.99	583.58	583.58
40%	249.48	222.36	724.09	724.09	599.83	599.83
-Pump 10%	249.48	200.81	739.44	739.44	627.22	627.22
25%	249.48	113.53	801.61	801.61	738.17	738.17
40%	249.48	7.49	882.72	882.72	878.00	878.00

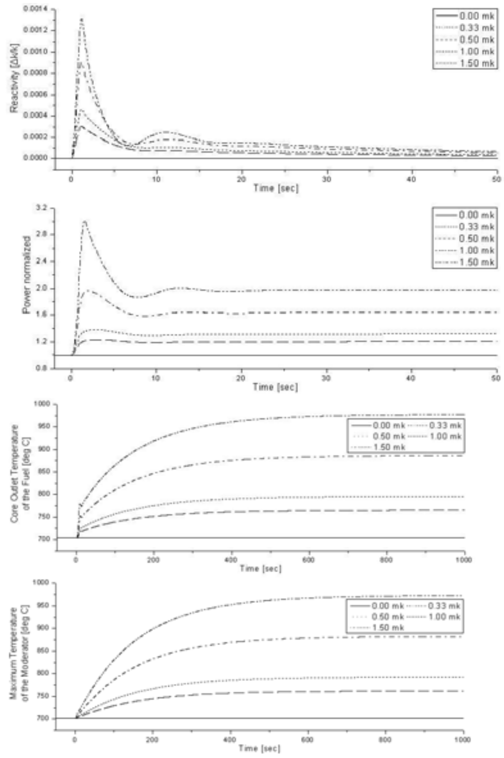

Fig. 3 Reactivity Insertion Transients

Both the table and figure stimulate the reactor system to be operable at very rare abnormal occurrences, which could be considered as a design-based-accident.

For example, if the reactor physics design criterion sets the maximum allowable excess reactivity to be less than 1.5mk, the AMBIDEXTER should never encounter a loss of regulation accident, while the fuel temperature stays below 900℃, the reactor outlet temperature of the AHTR.[3] Consequences of other cases should be more mild.

3. Conclusions

The AMBIDEXTER should be able to be designed as an inherently safe reactor on behalf of its self-regulation capability demonstrated in this study.

REFERENCES

[1] S.K. Oh, et. al., *Concept Synopsis of the AMBIDEXTER Nuclear Energy Complex*, presented in this conference, (2009).

[2] R.C. Robertson, et. al., *Conceptual Design Study of a Single-Fluid Molten-Salt Breeder Reactor*, ORNL-4541, ORNL, June(1971).

[3] C.W. Forsberg, et. al., *Status of Preconceptual Design of the AHTR*, ORNL/TM-2004/104, May (2004).