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Concept Synopsis of the AMBIDEXTER Nuclear Energy Complex

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1. Introduction

The molten salt reactor was originated from ORNL in 1950s, and continually evolving as the world nuclear society has faced with new challenges. Recently the Gen IV international forum added it into the R&D candidate cart, taking into account its potential value of fulfilling the technology goals for future nuclear energy systems.

The AMBIDEXTER [1] concept, an integral-type molten salt reactor system embeds in indigenous requirements, on top of the Gen IV goals, stemming from Korean nuclear perspectives. Figure 1 shows the schematic of the AMBIDEXTER nuclear energy complex, a coupling of the energy and radiation factories branched out from the reactor system.

Important design features of this integral plant are explained in following sections.

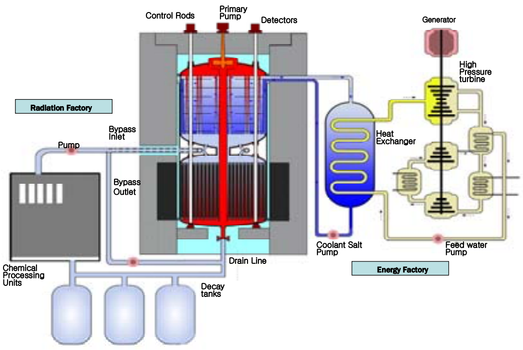

Fig. 1 AMBIDEXTER Nuclear Energy Complex

2. AMBIDEXTER Design Highlights

2.1 General Design Features

The AMBIDEXTER uses a liquid-phase fuel, fluorides compound of actinides and fission products, dissolved in 50NaF-46ZrF_4 solvent. The PWR spent fuel treated by the DUPIC OREOX[1] and fluorination processes, is used as the feed stock. By continuous reconditioning and feeding, the fuel salt maintains its nuclear quality as desirable for steady operation with minimum loading of the fissile.

The entire reactor system, which is confined in a single Hastelloy-X or -N vessel consists a pair of the reactor and heat exchanger compartments and a fuel salt pump. This integral configuration has many advantages, such as ignoring any possibilities of piping failures, confining the safeguard and security boundary, improving quality and work-load during erection, and so forth.

Small scale pyro-processing units, are lined up for the fuel salt reconditioning to function of removing surplus uranium and volatile fission products from the fuel salt by-pass line. Radio-nuclides separated can be reused as gamma sources for the on-site irradiator, which helps significantly reducing the strength of the source term at accidents and the load for HLW management as well.

2.2 Double-Bank Reactor Core

The reactor core is divided into two radial regions; the inner region forms a large central thimble in where the transmutation reactions for high resonance absorber TRUs are stimulated under the fast reactor environment; and the outer region is occupied by arrays of hexagonal graphite lattice where, through a circular flow channel the fuel salt flows, reacts with thermal neutrons and generates fission heat dominantly.

The fuel salt, thus, enters into the upper plenum of the reactor, flows downwardly in the fuel channels, mixes at the reactor lower plenum, moves upwardly in the central thimble and leaves for the heat exchanger up-riser.

Less than 10% of heat exchanger outflow of the fuel salt is bypassed to the on-site chemical processing units, reconditioned, and returns to the main recirculation flow at the reactor upper plenum.

2.3 Design Analysis Methodology

As for the fuel compositions of AMBIDEXTER, their changes during operation do not depend only on in-core irradiation history but also on dynamics of recirculation including continuous reconditioning processes and fuel feeding. Dual irradiation in the double-bank core must be taken into account. Figure 2 illustrates the computer code system developed and used for this study.

An iterative method using the coupled codes system consisting of HELIOS for spectrum calculation and AMDEC[2] for nuclide concentrations was successful to generate two converged lattice properties, one for the inner core and the other for the outer core.

For core calculations, AMBIKIN2D[3] was developed, verified and utilized to deal with both static and kinetics problems of the AMBIDEXTER reactor system, that should take into account fractional losses of delayed-neutron precursors entrained in fuel flow.

3. 250 MW_{th} AMBIDEXTER Performances

3.1 Design Characteristics

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

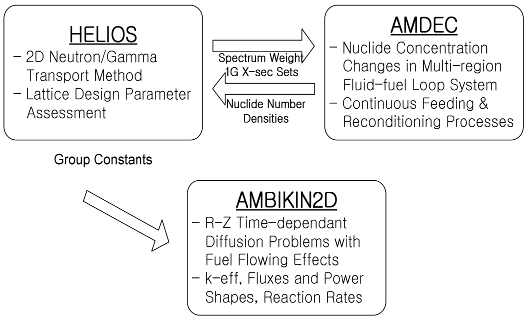

Fig. 2 Computer Code System for the AMBIDEXTER Neutronics

Table 1 depicts the preliminary design characteristics of the 250MW$_{th}$ AMBIDEXTER, the reference plant chosen for the concept viability studies.

Table 1. 250MW$_{th}$ AMBIDEXTER Design Data

Parameters	Values
- Reactor thermal power, MW	250.0
Inner core/Outer core	9.1/240.9
- Reactor vessel:	
Material	Hastelloy-X or -N
Dimension, DxH, cm	370x1200
- Reactor compartment:	
Dimension, DxH, cm	360x420
- Reactor core outer radius:	
Inner/Outer/Reflector, cm	45.2/169.2/180.0
- Reactor lattice:	
Shape/Material	Hexagonal/graphite
Flat-to-flat distance, cm	10.0
Fuel channel radius, cm	1.0
- Fuel salt:	
Material	NaF-ZrF$_4$ -RDUPIC
Composition, mole%	50.0-46.0-4.0
Total core loading of heavy elements, [g]	291,609
Daily feed rate, g of RDUPIC/d	1,838
- Reactor Physics:	
Effective multiplication factor	1.00284
Maximum neutron fluxes, x10^{14} nv	
Thermal(≤ 1.0eV)	2.768
Fast(≥ 50kev)	2.755
Reactivity coefficient, pcm/℃	
Fuel temperature	-1.4
Graphite temperature	1.2
Conversion ratio	0.298
Effective delayed neutron fraction	3.04x10^{-3}
- Thermal-hydraulics:	
Maximum power density, W/cm^3	14.0
Core inlet/oulet temperature, ℃	565.6/704.4
Max. graphite temperature	702.1
Flow velocity in inner/outer core, cm/s	76.5/161.8

The integral reactor vessel, a 3.7m O.D. and 12.0m high Hastelloy tank is divided into the heat exchanger and the reactor compartments between whom the central thimble provides the flow path for the fuel salt.

For ensuring steady power operation, 300kg of heavy elements of the core inventory has to be maintained by feeding 1.8kg/d of the reduced-DUPIC, equivalent to daily consuming 186kg of the PWR spent fuel and subsequently converting 98.6% of HLW to LLW class depleted uranium.

Nature of both very low excess reactivity and negative reactivity feedback ensures the rector not to experience prompt critical at any circumstances.

The present design of the AMBIDEXTER produces thermal energy with the salt temperature range of 700℃ but, in thermal margin aspect much higher operating temperature, e.g., 850~900℃, could be acceptable.[4]

3.2 Alternative Designs

Prime design goal of the AMBIDEXTER was set to maximum consumption of spent fuel without overriding the proliferation barrier. However, as the environmental issues become more critical than ever, concerns on the secure supply of uranium resource are growing.

Thorium has been noticed an excellent denaturant when mixed with the R-DUPIC for the AMBIDEXTER, which should help diversifying its fuel cycle strategy.

4. Conclusions

The technical facets of AMBIDEXTER-NEC concept was broadly discussed in respect of the future nuclear energy system requirements and was much accounted of special fits to Korean situations.

Established fuel cycle strategy of the AMBIDEXTER, based on the DUPIC experiences, should be technically feasible, economically compatible and socially intimate..

According to the 250MW$_{th}$ prototype plant design study, the sustainability goals in terms of fuel utilization, waste management and proliferation resistance will be noticeably enhanced, compared to the Gen III class reactors. The nuclear safety, also should be improved by inherent characteristics such as much smaller source term, large negative temperature feedback, negligible piping failure probability and very large thermal mrgin. Economic incentives of the AMBIDEXTER may be got from savings in fuel fabrication cost and in site erection workload.

REFERENCES

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