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Study on Conceptual Design Support System for Liquid Metal Reactor

Kwang Gu Lee and Soon Heung Chang

Department of Nuclear Engineering
Korea Advanced Institute of Science and Technology

ABSTRACT

Feasibility study on conceptual design tool for liquid metal reactor has been conducted to optimize the thermohydraulic and neutronic design parameters. To accomplish this task the neutronic code PRISM, fuel performance code and scaling method have been included into the conceptual design support system. ALMR(PRISM 303MWe) has been adopted as the reference plant and principally according to the power level, conceptual design parameters are optimized so that energy balance and neutronics balance seem to be satisfied. This paper presents only the results of optimization on primary system including the IHX system.

1. Introduction

The design of nuclear power pant require not only satisfaction of neutronic requirements and hydraulic characteristics but that of economics. The design need not to meet the technical factor but may meet just the economical factor. Therefore the nuclear power plant is difficult to be designed in the detail. Thus development of conceptual design tool that can illustrate the trend of main parameters from input should be needed to achieve the detailed design. For past decades the computer and the computer aid systems have been rapidly improved and developed and it is easy to perform the development of design tool. Therefore the calculations of neutronics and thermohydraulics can be easily achieved to simulate the design parameters for liquid metal reactor. Generally the fast breeder reactor adopts the hexagonal core - especially including metal fueled core of PRISM - and liquid metal (sodium) as the working fluid. The processes and the methodology that are accomplished to perform the caculations are difficult and different with the first generation nuclear power plant. To overcome these difficulties, this conceptual design support system is consist of several objects and their subobjects on basis of object-oriented structure. New liquid metal reactor from scaleup and scaledown by the scaling law keep the hydraulic characteristics. And the law simultaneously generates several design parameters to optimize the other design parameters for some objects or/and subobjects.

2. Overview of Design Concepts for LMR

Major Design Objectives

Table 1 lists the principal goals of breeder reactor design and the specific reactor design objectives that accompany the goals. Safe operation is mandatory for any nuclear reactor system. In terms of design objectives, safe operation translates into conscious awareness of safety at every stage of design. A high breeding ratio is needed to reduce fuel doubling time and therby allow a sufficiently rapid rate of introduction of breeder reactors after uranium resources become scarce. A very important objectives of any energy generating system, of course, is low cost. Hence, high burnup becomes an important objective, both for optimum utilization of high fissile content fuel and to minimize downtime for refueling.

- *core and blanket arrangements*
  Since the ability to breed fuel is the principal feature which distinguishes fast breeder reactors from thermal converter reactors, it is appropriate to ask how fertile and fissile fuels should be arranged to optimize breeding potential. This paper consider the homogeneous metal burner core.

- *system heat transfer*
  Neutron activation of the sodium coolant in the primary heat transport system of an LMFBR requires that a secondary, or intermediate, heat transport system also be employed in an LMFBR. Hence, sodium coolant in a primary loop is pumped through the core and circulated through an intermediate heat exchanger and a secondary sodium loop transports heat from the IHX to the stem generator. The temperature of the sodium leaving the reactor is substantially higher than the coolant in an LWR. Thus steam temperatures in the LMFBR are higher. Two different arrangements in which the radioactive sodium in the primary loop must be shielded can be used.

Table 1. Principal goals of breeder reactor design

Content	Accompanying Design Objectives
Safe Operation	Reliable Components Adequate Containment Margin
High Breeding Ratio	High Neutron Energy
Low Doubling Time	High Breeding Gain Low Fissile Specific Inventory
Low Cost	High Burnup Compatibility with LWR Cycle Minimum Capital Costs

3. Strategy for Conceptual Design Optimization

Global Feature of Design Procedure

Among the above candidates of LMRs the reference plant must be adopted for initiating the evaluation. from the inherent passive characteristics and the economical merit From these requirements, one can dedue that *Advanced Liquid Metal Reactor* be the best option. RVACS (Reactor Vessel Auxiliary Cooling System) that ALMR has is the most outstanding inherent cooling system for decay heat removal. The lower hot temperature in comparison with the other reactors will enhance the plant safety. So in this system, as the reference plant ALMR(exactly PRISM) was adopted.

‣ *design optimization program*

The following figure presents the technical tree for design evaluation of this conceptual design support system. Briefly, this system contains the two objects: one is the core ddesign evaluation system and the other is the validation tool which support and enhance the output-parameter from this design support system. Besides these objects, the following subobjects are consist of the design supporting object. These subobjects are based on the rule-based inference technology.

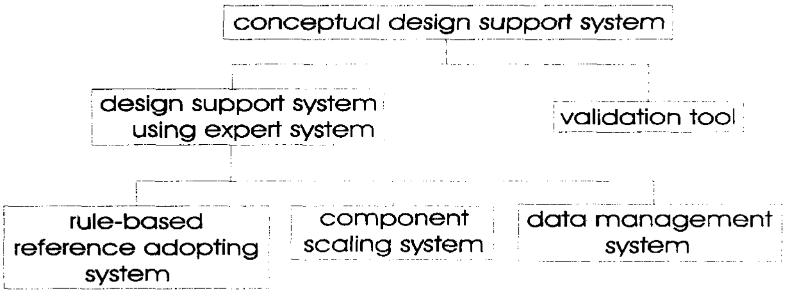

Fig. 1. Technical tree for Design Support System

In this system, design procedure for evaluation in aspect of software is like the followings.

- electrical power level as input
- adoption of reference plant (including the core configuration)
- adoption of mechanical and safety features from power level
- adoption of heat exchanger types by plant characteristics
- optimization of main parameters and scaling of systems
- validation of output parameters

‣ *parameter selection*

Initially only the major design parameters must be considered in an effort to maintain a clear overviwe of plant operation and to identify correctly the various parameter interrelations.

The 'major' temperatures are :

• primary △T : $T_C = \beta + T_{PC} + \alpha \Delta T.$

where T_C = clad temperature

T_{PC} = primary cold temperature

$\triangle T$ = primary sodium temperature rise

- steam generator water inlet temperature T_w
- turbine inlet steam temperature T_v

Strategies for Design Optimization in Each Component

- *Core Design*

The Fig.2 stands for the process that would calculate the core geometry the core properties ; average power density, power peaking factor, number of fuel assembly and etc. Initially, the value of power peaking factor must be guessed for initiating the core analysis in basis of reference core. And maximun power density should be fixed at standard value resulting from the reference core design. Therefore from the foloowing process the core design can be initiatied with some rough assumption.

- *thermamohydraulics and structural design*

Choosing the both temperatures is the initial point in this design system. In this paper to slove these problems, two methodology shoud be used ;One is the similarity law and the other is the thermodynamic calculation by fuel performance analysis.

Scaling criteria developed by Ishii and Kataoka is used to obtain the preliminary conceptual design parameters for liquid metal reactor forced and natural circulation pool system under single-phase flow conditions. In the following table, l_R and a_R present the ratio of length and cross sectional area respectively.

Table 2. Results from scaling law for real time simulation

scaled quantity	M/P ratio
length	l_R
hydraulic diameter	1
flow area	a_R
volume	$a_R\ l_R$
velocity	l_R
time	1
system pressure & solid structure properties	1
heat generation/unit volume/unit time	l_R
power	$a_R\ l_R^2$
heat flux	l_R
heat tranfer coefficient	$l_R^{0.591}$
# of rods or pipes	a_R

Fuel performance program accomplish the evaluation on peak temperatures of each part at core region ; peak coolant outlet temperature, peak clad surface temperature, peak fuel surface temperature, peak fuel centerline temperature, and burnup. To accomplish the above evaluations this fuel performance program must use the average linear power density, coolant inlet temperature and outlet temperature, neutron flux from object for core design and etc. Using the value of core temperature difference from scaling law and the themperature margin from the reference reactor fuel performance program iterates the core outlet temperature so that the results would be satisfied with design limits.

4. Conclusion

From the above processes this paper presents the conceptual design results of primary system including the IHX at power level of 450MWe.

Table 3. conceptual design parameters at power level of 450MWe

		303MWe	450MWe
core	equivalent diameter	292 cm	358cm
	height	107cm	109cm
Rx vessel	equivalent diameter	912 cm	1138cm
	height	1936cm	2416cm
	IHX inlet hole	1493cm	1875cm
	sodium level	1742cm	2146cm
containment vessel gap size		33.12cm	40cm
RVACS	riser	25.4cm	21.44cm
	downcomer	43.1cm	33.5cm
IHX	secondary inlet temperature (℃)	325	323
	secondary outlet temperature (℃)	477	478
	heat transfer capacity (MW per IHX)	424	638
	heat transfer area (m^2)	2000	3060
	# of tubes per IHX	5519	8295
	IHX dimension (mm)	1073×4991	1315×6119
	tube length (mm)	7263	7394

Table 4. core thermal performance at power level of 450MWe

fuel performance items	303MWe	455MWe	limits
primary hot leg temperature (℃)	498	499	
primary cold leg temperature (℃)	356	354	
Peak clad temperature (°F)	1128	1074	
Peak fuel surface temperature (°F)	1152	1101	1300
Peak fuel centerline temeprature (°F)	1535	1403	1735
Peak burnup (MWd/KG)	148.4	135.14	

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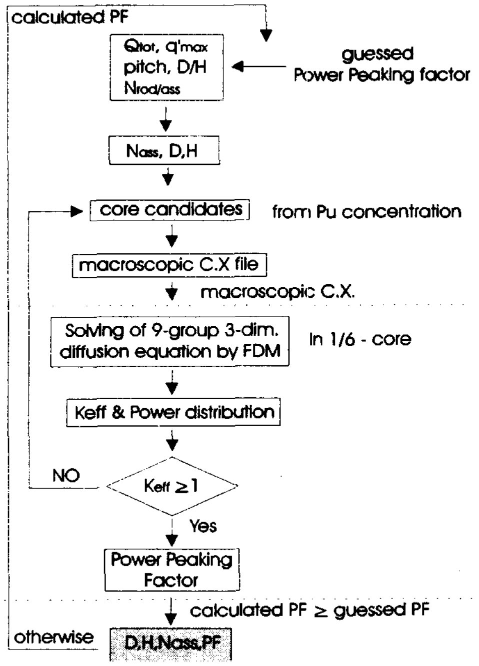

Fig. 2. Flow chart for the core analysis including the neutronics code

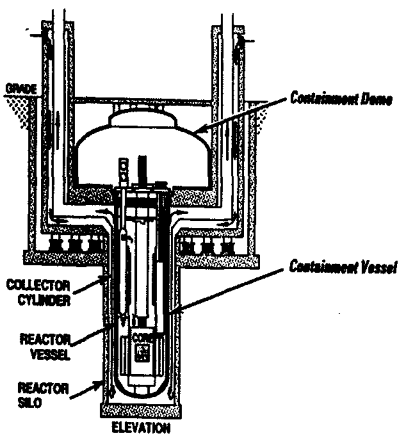

Fig. 4. ALMR containment configuration including RVACS

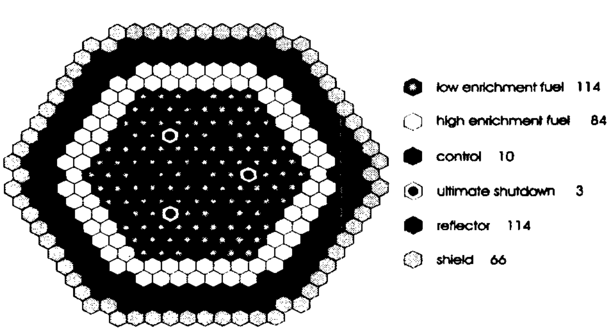

Fig. 3. Metal burner core with 19.2 w/o Pu - 10 w/o Zr fuel at peak linear power 15kW/ft

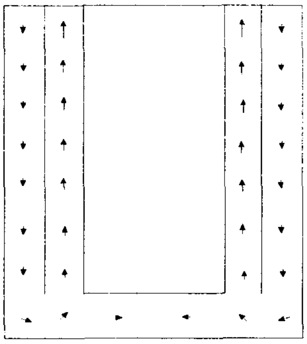

Fig. 5. RVACS performance at 1.2% full power