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# Preliminary Conceptual Design for a Prototype Experimental Sodium-cooled Fast Reactor

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## 1. Introduction

Intensive R&D activities have been done for the Generation IV fast reactors with viable goals; such as improvements in safety and economics, fuel cycle sustainability with proliferation resistance. Sodium cooled fast reactor (SFR) development has been a part of South Korea's long term R&D plans, which includes the design, validation and construction of prototype SFRs.

In case of prototype reactor, neutron economy is not good enough with a smaller core size to overcome large neutron leakage, however, high level of flux is required for material irradiation test with longer cycle length. Furthermore, enough reactivity and thermal margin should be ensured in order to accommodate various test fuels under test. Therefore, conceptual design of an experimental reactor is more challenging than commercial works for demonstration plants.

This work is in the early stages of conceptual design for Multipurpose Experimental Sodium-cooled Fast Reactor (MESOF) in the reactor size of prototype that is aimed for operational validation with experiments and testing of fuels and materials. In this study, parametric scoping calculations were done for the optimum core design. A detail performance check will be done for test zones and core under the generic safety constraints. One of the urgent works will be the determination of possible range of operational conditions.

## 2. Methods and Benchmark Results

Based on the published data from prototype and experimental fast reactors, design requirements and goals of MESOF were set. A simple validation works for existing code systems were done comparing with reference data for ABTR designed in Argonne National Laboratory [1]. TRANSX, DANTSYS and REBUS-3 code have been used for lead-cooled fast reactors in Kyung Hee University after validation to MCNP [2]. KAFAX-F22 library published by KAERI was used in this study. [3].

### *2.1 Design Targets of MESOF*

The experimental & prototype fast reactor design requirements were determined as the followings.

Table I: Design Requirements of MESOF

| | | |
|---|---|---|
| Design Targets | Power | (300MWt) >100 MWe |
| | Flux Level | Avg.> 3.0E+15 n/cm2-s |
| | CR worth | No one CR < 1.0 $ |
| | Cycle Length | > 4 months (120 days) |
| | Fuel | LEU U-10Zr<br>enrichment < 20% |
| | Alternative Core Options | LEU UO2,<br>LEU-TRU-10Zr<br>(with LWR SF recycle) |

### *2.2 Code Validation with ABTR Benchmark Problem*

The validation of code system was done against the reference ABTR data [1]. Unknown data for material and geometry were estimated through the database about ABTR. Available REBUS-3 code has only a nodal diffusion module, DIF-3D, which shows relatively large difference compared with transport theory code. REBUS-3 code in Korea does not include a transport calculation option, VARIANT.

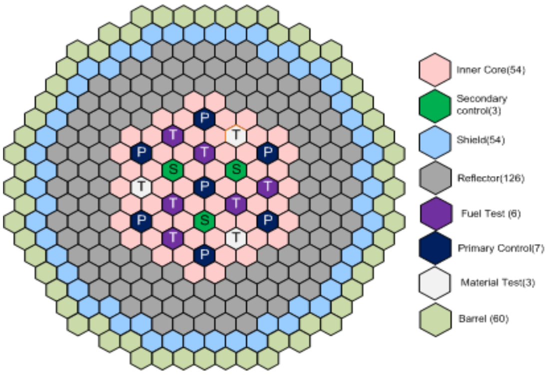


Fig. 1. ABTR Core Configuration

Fig.2 shows the comparison of k-eff of ABTR resulted from REBUS-3, MCNP and ERANOS. Nodal diffusion model in REBUS-3 underestimated K-eff. by about 2% from MCNP, however agree with ERANOS by about 0.1%. There is an apparent limitation of diffusion model for small sized core problems. Therefore, a use of proper correction factors should be developed for detail design stage.

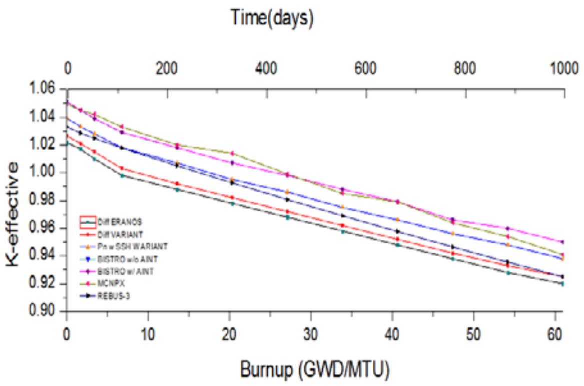
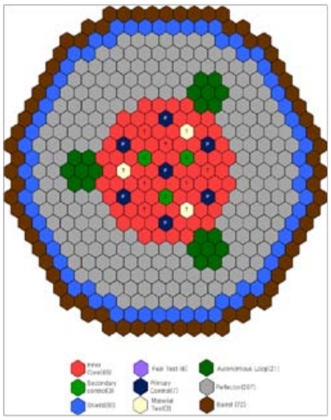


Fig. 2. K-effective variation to burnup of MCNP, ERANOS and REBUS-3 models.

## 3. Preliminary Core Design

ABTR inner core configuration was adapted in MESOF design. However unlike ABTR with TRU fuel loading, MESOF was loaded with LEU fuel. In order to compensate the loss of reactivity from LEU, more fuel pins are to be loaded in a larger size assembly. Fuel assembly design was done through a parametric study with database for U-Zr metal fuels tested in EBR-II [4]. The other assemblies for reflector, shield, and control were designed with the same specification with ABTR [1]. A parametric Study was performed to satisfy the cycle length by varying the fuel pin height and number of reflector assemblies around the core. From this study, fuel pin heights was determined as 87cm and number of reflector assemblies was 168.

For an experimental reactor in prototype reactor class, there should be test assemblies for both fuels and materials for the purpose of in-pile irradiation tests. In this study, the same locations and number in ABTR were chosen. In addition, separate and independent irradiation loop is needed for the irradiation experiment of fuels under different coolant or at different operation conditions. Thus, Autonomous loop (independent fuel test loop) was placed in the outer reflector zone.



| | |
|---|---|
| Assembly Pitch, cm | 16.142 |
| Inter-assembly gap, cm | 0.432 |
| Duct outside flat-to flat distance, cm | 15.71 |
| Duct material | HT9 |
| Duct thickness, cm | 0.394 |
| Active core Height, cm | 87 |
| Number of inner driver | 72 |
| Number of Autonomous Loop | 3<br>(21 Assembly Area) |

Fig. 3. Reactor core configuration and design features

Installation of autonomous loop reduce some amount of excess reactivity. Therefore, number of reflector assemblies was increased to 207 in case of core with autonomous loop. For the feasibility test, extreme cases were calculated. The following table shows a case with U-Zr fuel in all fuel test assembly locations and reflector assemblies in all material test assembly locations. Autonomous loop has only Na coolant without fuel. This is an example of many candidate cores with different combinations of test operational conditions.

Table Ⅱ: Performance Characteristics

| | |
|---|---|
| Reactor power, MWth | 300 |
| Cycle length, effective full power days | 120 |
| Number of driver assemblies | 72 |
| Fuel form | U-10Zr |
| U enrichment, % | 19.5 |
| Initial core loading (heavy metal /Fissile), MT | 6.16 / 1.20 |
| Power density (average/peak), kW/l | 212.23 / 414.87 |
| Burnup reactivity swing (%ΔK) | 0.88 |
| Power peaking factors (BOEC/EOEC) | 1.95475/ 2.02298 |
| Peak linear power, kW/m | 34.67 |
| Linear power limit, kW/m | 44.0 |
| Core average flux, $10^{15}$ n/cm$^2$-s | 1.69 |
| Material Test Assembly flux, $10^{15}$ n/cm$^2$-s | 1.94 |
| Fast flux fraction | 0.69 |

## 4. Conclusions

Calculation with Autonomous Loop core seems to achieved target cycle length but with lower flux level than the design target. Therefore, test should be done for the two cycle periods in order to increase time length. As next step, MCNP analysis will be done for the detail design work and performance evaluations. The use of nodal diffusion model at this stage may not bring significant problems in design works because underestimation of k-eff due to leakage can be concerned with reasonable adjustment.

## REFERENCES

[1] Allen, K., et al., “Benchmark of Advanced Burner Test Reactor model using MCNPX 2.6.0 and ERANOS 2.1,” Progress in Nuclear Energy (2011)

[2] Jae-Yong Lim, Myung-Hyun Kim, "A New LFR Design Concept for Effective TRU Transmutation" Progress in Nuclear Energy, Vol.49, No.3, pp.230-245, April, (2007)

[3] J. D. Kim, C. S. Gil, "KAFAX-F22 : Development and Benchmark of Multi-Group Library for Fast Reactor Using JEF-2.2-Neutron 80 Group and Photon 24 Group," KAERI/TR-842/97, (1997)

[4] D.C. Crawford, D.L. Porter, S.L. Hayes , “Fuels for sodium-cooled fast reactors: US perspective,” Journal of Nuclear Materials, Vol.371, pp.202-231, 2007