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〔技術情報グループ〕

THE ACCURACY IN THE PREDICTION

OF PHYSICS PARAMETERS OF FAST

BREEDER REACTOR

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compiled by

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The Accuracy in the Prediction of Physics Parameters
of Fast Breeder Reactor

complied by

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1. Introduction

In the framework of the reactor physics in PNC Fast
Breeder Reactor Project, the principal object of fast
reactor physics activities is to provide a reliable basis
for the prediction of physics parameters of a fast power
reactor under consideration. Therefore, evaluation and
improvement of cross section sets, a series of mock up
critical experiments and their analyses, and development
of calculation methods have been intensively studied since
1968. Overall schedule of LMFBR programme, together with
reactor physics activities, is shown in Table 1.

In 1971, the accuracies of various physics parameters
in regard to the design of "JOYO" core were estimated by
the extrapolation of the results obtained from the mock up
experiments for "JOYO" core and their analyses. (see Table
3).

Since 1971, a series of mock up experiments and analy-
ses for "MONJU" core, in which the MOZART programme as full
scale mock up experiments and the FCA programme as partial
mock up experiments are included, has been under way.

A great deal of integral data obtained from the mock
up and bench mark assemblies have been analized to check
the validity and make the improvement of design calculation
methods including cross section sets, and the accuracies in
the prediction of physics parameters of a prototype fast
breeder reactor has been preliminary estimated by three
major industrial companies in the end of 1973.

This evaluating work of the accuracies has been aimed to
find sound bases for further necessary research activities
in comparison with the required accuracies for the core
design of "MONJU" and the target accuracies which are chosen
values.

2. Estimated Accuracies

In order to predict, as accurately as possible physics parameters of fast reactors, two main procedures, which are complementary each other are considered.

The first procedure is to confirm the validity of design calculation systems through the modification of cross section sets and calculation methods for improving the agreement between measured and calculated integral parameters on a wide range of benchmark type assemblies.

The second one is a method of predicting directly the physics parameters of the specific fast reactor by the extrapolation of E/C (experiment over calculation) ratios obtained in the mock up assemblies which simulate the core to the reactor. We call this method "Bias Method".

Both procedures are used intensively in Japan, because the status of prediction based on the first method is at present not satisfactory and the prediction on the basis of the Bias Method may introduces rather large uncertainties due to the differences between the mock up assemblies and the reactor.

In 1971, the physics parameters of the "JOYO" core were predicted on the basis of the results obtained from the mock up experiments for the "JOYO" core and the accuracies of physics parameters were estimated. At that time, the prediction of physics parameters were not based on a definite model, but the estimated accuracies were reasonable against the required accuracies for the design because of large design allowance. The estimated accuracies for "JOYO" are shown in Table 3, together with present accuracies.

The present accuracies have been estimated, in the end of 1973, in the prediction of the physics parameters of a prototype fast breeder reactor on the basis of the mock up experiments for the "MONJU" core (Bias Method). In this case, a model of the extrapolation of the results obtained from the mock up experiments to the designed reactor has been fixed and the sources of uncertainties in this model have been picked up without omission. Fig. 1 shows the flow diagram of the extrapolation model which are used here and the relevant uncertainties.

The sources of uncertainties are assorted as follows.

A   Uncertainties due to the experiments
   A-1   Experimental errors
      (a)   measurement
      (b)   deduction

   A-2   Errors caused by correction for the peculiar quantities to the assembly
      (a)   heterogeneity
      (b)   atomic density, impurities
      (c)   temperature

   A-3   Errors due to calculation
      (a)   nuclear data and constants
      (b)   calculation method

B   Uncertainties due to the extrapolation
   B-1   Errors caused by differences of atomic density

   B-2   Errors caused by differences of size, configuration (pattern)
      (a)   pin heterogeneity
      (b)   Na channels for control rods
      (c)   peripheral conditions

B-3 Errors caused by difference of temperature

C Uncertainties due to the specification of designed core

  C-1 Errors caused by uncertainty of composition

    (a) deviation from the nominal value of the specification within allowance

    (b) uncertainty in the prediction of burn up

  C-2 Errors caused by uncertainty of operating temperature

According to above classification, the estimated accuracies in the prediction of criticality, power distribution, control rod worths, breeding ratio, and doppler and sodium void reactivities on a prototype fast breeder reactor are summarized in Table 2, and their total accuracies are compared with target accuracies in Table 3.

The numerical estimation has been performed with 90% confidence level, assumming that all sources of uncertainties considered here are independent elements and are able to be treated as statistical errors. Therefore, numerical figures presented here are not final ones, but still under discussion, and some of them may be revised and classification of uncertainties may be also changed according to further studies on how to extrapolate the results obtained in the mock up experiments to the designed reactor and how to accurately analize and correct the experimental data with sufficient accuracy.

3. Target Accuracies and Further Necessary Research Activities

Target accuracies, shown in Table 3 are not based on any specific commercial fast breeder reactor. They are chosen values for making a target of further research

activities in reactor physics, and it is assumed that they are able to be attained within the next five years. In Table 3, the target accuracies are compared with the present estimated accuracies based on the mock up experiments for "MONJU".

As the selection of target accuracies is based on the experience obtained through the studies on nuclear characteristics of preliminary design for a commercial FBR (1,000 ~ 1,500 MWe) and the estimation work of present accuracies, it seems that these target accuracies are at present not excessive for a large fast power reactor. However, some of the target accuracies may be revised according to further studies on comprehensive analyses of a great deal of integral data, especially integral data on burn up fuel assembly. In addition, it is anticipated that some of the target accuracies may be higher (or lower) than the required accuracies for design commercial FBR at the time when the design will be definite.

In order to attain the target accuracies as soon as possible, the further research activities which must be studied by priority have been estimated by comparison of the target accuracies with the estimated accuracies. Further research activities necessary to providing a sound basis for design of a large fast breeder reactor are summarized in Table 4, in which the ratio of the estimated accuracy to the target accuracy are given as a measure of the priority.

It is at present a question whether the mock up experiments for a large FBR is necessary or not to attain the target accuracies, but it is generally recognized from Table 3 and 4 that the experiments on burn up fuel assembly are more necessary than the experiments on clean fuel assembly.
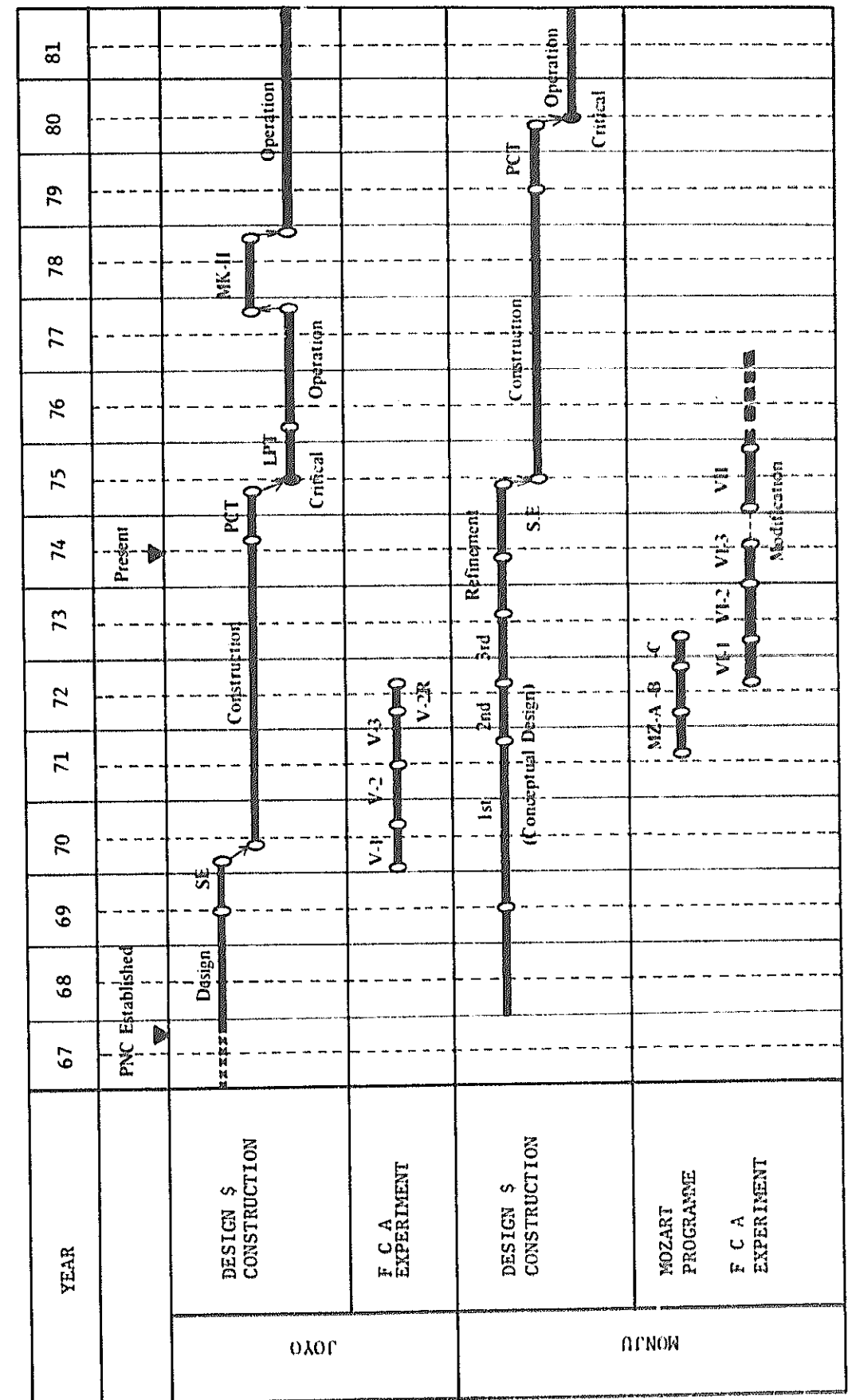
4. Concluding Remarks

The present accuracies in the prediction of physics parameters of prototype fast reactor "MONJU" have been preliminary estimated on the basis of the results obtained in the mock up experiments and these estimated accuracies, except some of them, meet the required accuracies from the design.

Target accuracies which are described in this report are chosen values for making a target of further research activities, but at present not estimated ones based on any specific commercial fast breeder reactor. However, as it seems that these target accuracies will sufficiently cover the required accuracies for a commercial fast breeder reactor in the near future, the target accuracies are used, for the present, as the goal of reactor physics activities for a commercial FBR, comparing with the present estimated accuracies.

Finally, it is expected that the basis of the target accuracies for a commercial FBR will be clearly defined by establishment of the required accuracies for a commercial FBR together with the progress of design study.

Table 1. LMFBR development and reactor physics programmes

YEAR	67	68	69	70	71	72	73	74	75	76	77	78	79	80	81

JOYO — DESIGN & CONSTRUCTION; F C A EXPERIMENT

MONJU — DESIGN & CONSTRUCTION; MOZART PROGRAMME; F C A EXPERIMENT

SE = Safety Evaluation. PCT = Pre-Critical Test MK-II = Modification to Mark-II Core
LPT = Low Power Test

Physics parameter / Source of uncertainty	Keff fresh	Keff burn up	Power distribution core	Power distribution blanket	Control rod worth regulating	Control rod worth safety	Breeding ratio	Doppler coeff.	Na-void coeff.
A. Uncertainties due to experiments									
A-1. measurements	0.04		0.4	4.6	3		1	6	2
A-2. correction, deduction	0.3		-	1.5	0.5		1.5	9	5
A-3. calculation	0.1		3	4.2	5	7	4	3	15
sub total A[2]	0.3		3	6.4	5.8	7.6	4.3	11	16
B. Uncertainties due to extrapolation									
B-1. difference of atomic density	0.3	0.6	-	2	1	2.2	1	3	10
B-2. difference of size, configuration		0.3	2.2	3	3	5.8	2	6	11
B-3. difference of temperature	0.1		-	-	-	-	-	10	5
sub total B[2]	0.4	0.7	2.2	3.6	3.2	6.2	2.2	12	15
C. Uncertainties due to specification									
C-1. manufacture	0.5		2.2 ±[3]	5	-	.	0.5	-	3
C-2. operation, burn up	0.1	0.4	2.2	5	1	1	0.7	-	-
sub total C[2]	0.5	0.6	2.2	5	1	1	0.9	-	3
total[2]	0.7	1.0	4.4	8.9	6.7	9.9	5	17	23

1) 90% confidence level (±%)

2) geometrical combination of uncertainties

3) included in hot spot factors

Table 3. Comparison of target accuracies and estimated accuracies in the prediction of physics parameters of fast reactor

Physics parameter	Estimated accuracy[1] 1971[2]	1973[3]	Target[1] accuracy
Keff			
fresh core	1.5	0.7	0.5
burn up core	.	1.0	0.7
Power dist.			
core	3	4 ~ 5	3
blanket	10	9	5
Control rod worth			
regulating	20	7	5
safety	20	10	7
Breeding ratio		5	3
Doppler coefficient	30	17	10 ~ 15
Na-void coefficient	30	23	10 ~ 15

1) 90% confidence level (±%)

2) experimental fast reactor "JOYO"

3) prototype fast reactor "Monju" not included βeff error (~4%)

Table 4. Further research activities in fast reactor physics

| Physics parameter	Estimated accuracy / Target accuracy		Further research activities
Keff (fresh)			
Pu mass	1.4	1.0	systematic estimation of manufacturing allowance
heterogeneity		0.6	experiments on bunched core and their analyses
control rod channel effect		0.6	criticality of nonuniform core with control rod channel
(burn up)			
heigher Pu, F.P. effects	1.5	0.9	integral check of heigher Pu and F.P. cross sections) experiments on
operation		0.6	confirmation of burn up calculation) burn up assemblies
Power dist. (core)			
calculation	1.5	1.0	confirmation of calculation method for flux tilting with off center control rods
extrapolation		0.7	experiments on uniform and nonuniform cores especially with irregularity
operation		0.7	confirmation of burn up calculation with partially inserted control rod
(blanket)			
operation	1.8	1.0	confirmation of burn up calculation in the blanket region
measurements		0.9	development of measurement techniques for γ dose and $238U$, $239Pu$ reaction rate distributions
calculation		0.8	experiments for γ-heating, control rod effect
Control rod worth (regulating)			
calculation	1.4	1.0	confirmation of 2-D transport and 3-D diffusion calculation, experiments of control system worth
(safety)			
calculation	1.4	1.0	study for B-10 enrichment effect, shadow and anti-shadow effects
extrapolation		0.8	experiments of safety rod system worth
Breeding ratio			
calculation	1.7	1.3	integral check of α^{49} and C^{28}
Doppler coefficient			
extrapolation	1.5	0.9	Doppler measurement of $238U$ to high temperature (~ 3,000°K)
deduction		0.8	evaluation of thermal properties; e.g.: thermal conductivity, gap conductance.
Na-void coefficient			
calculation	2.0	1.3	evaluation of streaming effects especially at off center by 2-D transport calculation
control rod effects		0.9)	experiments of control rods, higher Pu, F.P. effects
burn up effects		0.9)	
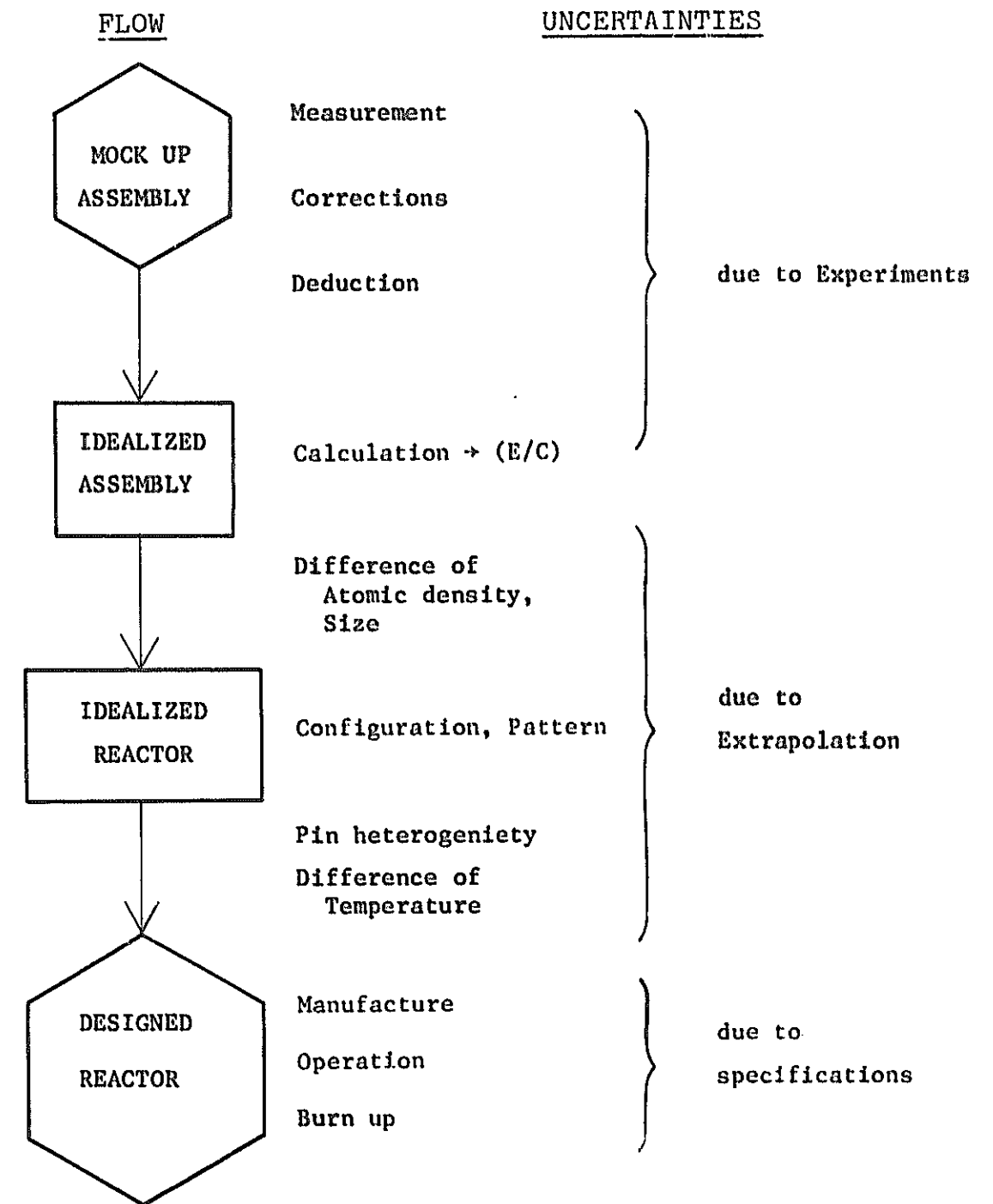
Fig. 1. Flow diagram of extrapolation and relevant uncertainties