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Current and Future Computation in Nuclear Engineering

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Current and Future Computation in Nuclear Engineering

Hiroshi Sekimoto

Tokyo Institute of Technology

Abstract. This paper consists of two parts. In the first part, current computations in nuclear engineering are presented, where areas of nuclear engineering, procedures for solution, limits of analysis, and increases of computer performance are explained. In the second part, future computations in nuclear engineering are presented, where two examples are discussed. One example is computations for innovative nuclear reactors. The other is computations for accident management.

1. Introduction

From the start of nuclear energy development, computation was a key technology for nuclear reactor design and operation. The computer development is one of the largest development among of scientific technologies. And the nuclear engineering computation becomes more and more accurate and sophisticated along with this development.

In the first part of this paper, current computations in nuclear engineering are presented. It covers the areas of nuclear engineering, procedures for solution, limits of analysis, and development of computer power.

In the second part, computations in future nuclear engineering are discussed, where two examples are presented. One example is computations for innovative nuclear reactors. The other is computations for accident managements which should be implemented in actual reactor operation system

2. Current Computation in Nuclear Engineering

2.1. Areas of Numerical Analyses in Nuclear Engineering

The important areas of numerical analyses in nuclear engineering are shown in table 1. They covers so many different kinds of calculation techniques. The present paper discusses mainly on nuclear reactors, since we have only a limited number of pages.

For each area we have many sub-areas to be analyzed by calculation, for example, the fuel cycle, which covers mining, enrichment, fuel fabrication, reprocessing, waste disposal, and fuel transportation. On the other hand some areas may be overlapped, for example, the cost is often investigated with optimization.

Required computation method usually differs in different areas.

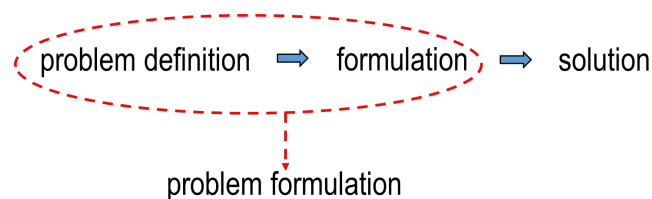


Table 1. Areas of numerical analyses in nuclear engineering

cross section evaluations,
reactor physics analysis (mainly neutron transport),
thermal aspects including fluid behaviors,
instrumentations and control,
stability, operations research,
stress analyses of solid components,
diffusion of materials especially in fuel elements,
fuel cycle including wastes disposal,
safety and accidents,
secularity,
environmental effects of radioactive materials from facilities, environment dynamics,
effects of irradiations on materials and human body,
designs of reactor system and elements,
costs,
optimization,
others.

2.2. Procedures for Solution

The general procedures for solution is shown in figure 1. Usually problem definition and formulation are combined and called as problem formulation.

**Figure 1.** Procedures for solution

Albert Einstein said “The formulation of a problem is often far more essential than its solution. [1]” This is true especially for physics. However, for the present nuclear engineering the problem is already presented and our jobs are usually solutions.

Many calculation methods are available for solving these problems. The problems for neutron transport are given by differential and/or integral equations. Usually these equations are transformed to matrix equations by employing discretization of continuous variables such as spatial coordinates, time, energy and angle. Electric computer is powerful for solving these equations. The neutron transport is also solved by Monte Carlo method, where discretization of continuous variables is not necessary. Since each method has its original merits and demerits, we should be careful for choosing proper method for each problem.

For safety analysis, we usually employ probabilistic risk analysis (PRA) which include event tree analysis and fault tree analysis. These analyses are entirely different from the neutron transport analysis. For this kind of problem, difficult part is not solving equation, but obtaining proper inputs.

We meet often optimization and stability problems. These analyses are also very different from the neutron transport analysis. Especially we have so many unique optimization methods from analytical to heuristic. We need to be familiar to these methods.

Figure 1 shows the only one direction from the problem formulation to solution, but after obtaining a solution we should check the whole procedure and change the problem formulation and/or solution, if necessary.

2.3. Limits of Analysis

When more contents are included in the analysis of problem, we can get more informative results. More general results can be obtained by treating wider problem region. More accurate results can be obtained by changing the assumption employed for the calculation to less approximated. More accurate results are obtained when number of calculation meshes is increased and convergence criteria are changed to be smaller. These improvements of analysis increase the computation size. The computations are usually performed by using computer. Both of the accuracy of results and problem size are limited by computer performance as shown in figure 2.

$$(\text{Accuracy of Results}) \times (\text{Problem Size}) < (\text{Computer Performance})$$

Figure 2. Limits of analysis

2.4. Increase of Computer Performance

The computer performance is increasing according to Moor's law [2] "the number of transistors in a dense integrated circuit doubles approximately every two years" for many years as shown in figure 3.

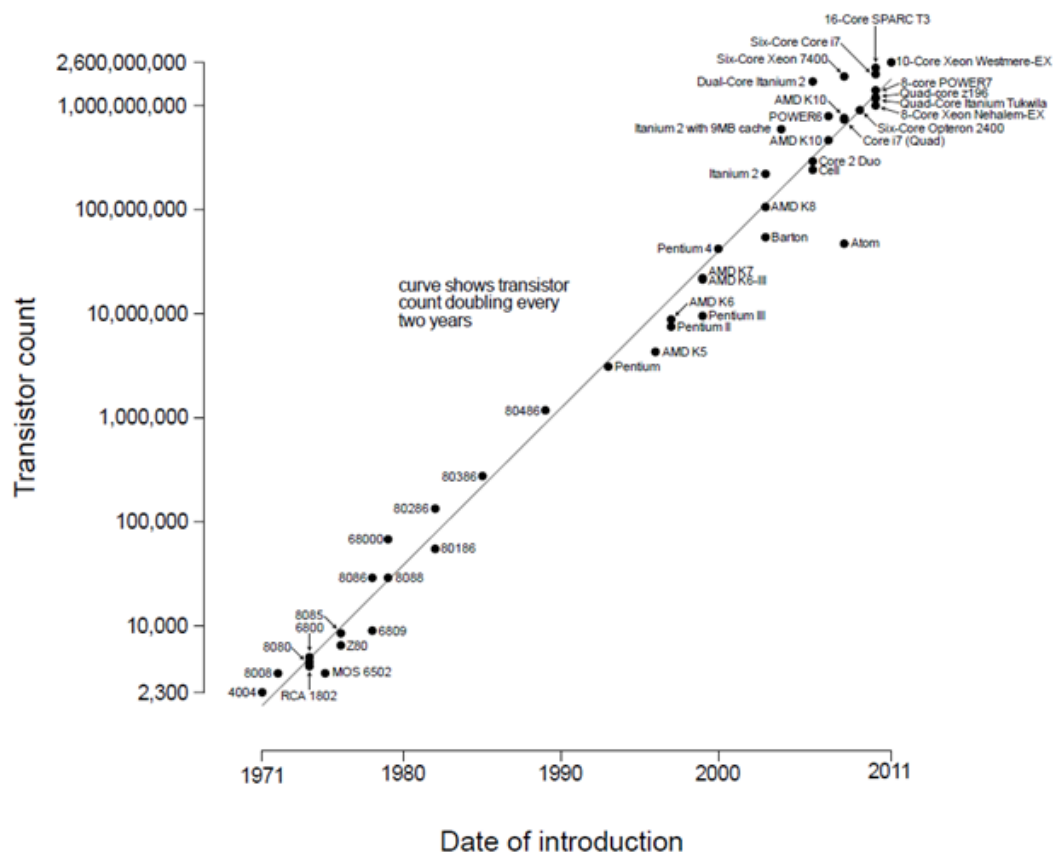
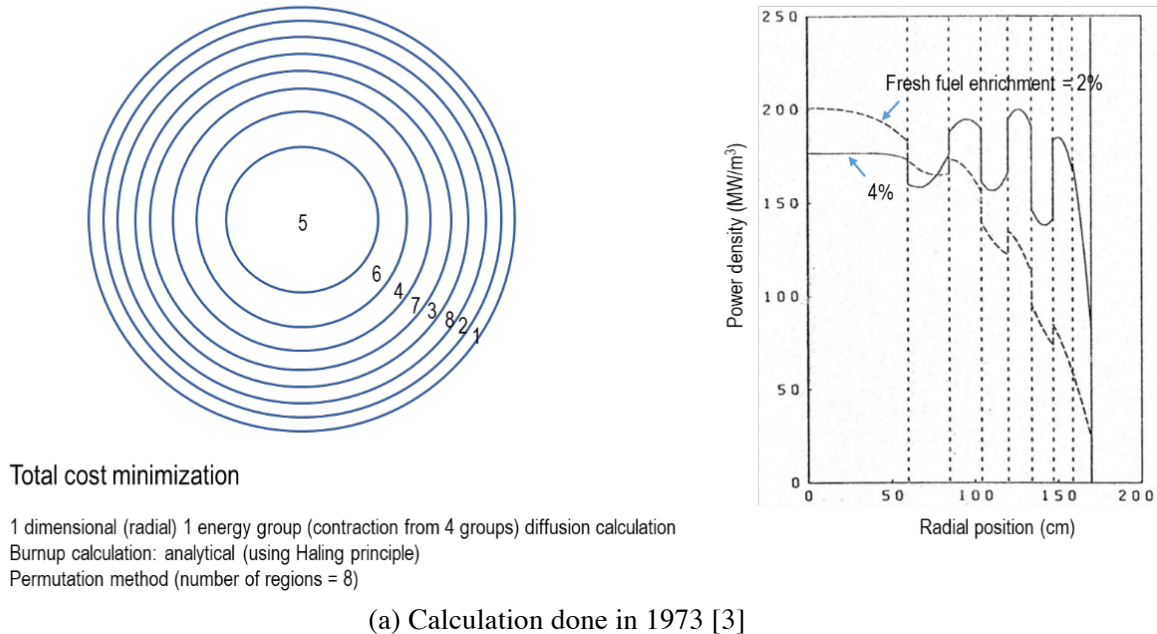


Figure 3. Increase of computer performance: microprocessor transistor counts 1971-2011 [2]

The change of this computer performance enables the larger computation in the later years. One example is shown in figure 4, which is in-core fuel management problem.

PWR In-core Fuel Management

H. Sekimoto & T. H. Pigford, 1974



LBE Cooled Fast Reactor In-core Fuel Management

V. Toshinsky, H. Sekimoto & G. Toshinsky, 2000

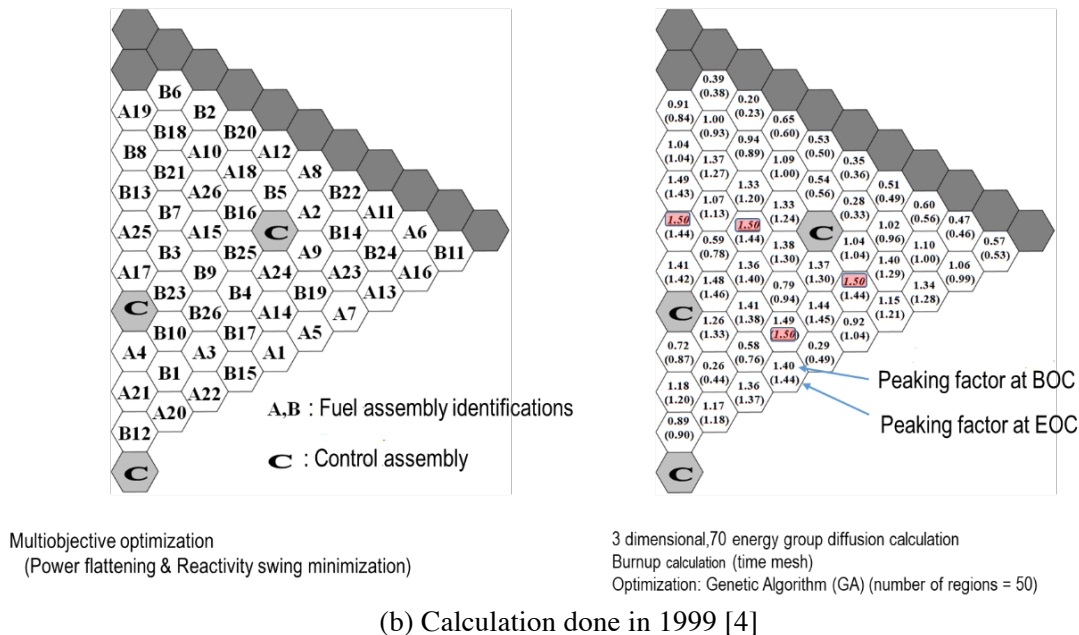


Figure 4. Effects of increase of computer performance on actual reactor analyses

In-core fuel management needs to treat a lot of space meshes for treating fine fuel assembly positions and a lot of cases for different fuel shuffling scheme. In 1973 it was impossible to treat actual fuel shuffling scheme of each fuel assembly. The calculation presented in figure 4 (a) treated cylindrically divided core which is not realistic [3]. In 1999 treatment of each fuel assembly became possible as shown in figure 4 (b) [4]. The total mesh numbers including energy groups increased by more than 10^4 ,

and the number of regions increased 5.6 times which increased the number of shuffling patterns so drastically. The used computers were the large computers in university computer center: University of California, Berkeley for the calculation (a) and Tokyo Institute of Technology for the calculation (b). Both machines had the world highest level of performance at each time. This situation is shown in figure 5. The treatable problem size increased so much by the increase of computer performance. However, not only computer performance but developments of analytical method also contributed to the great increase of problem size.

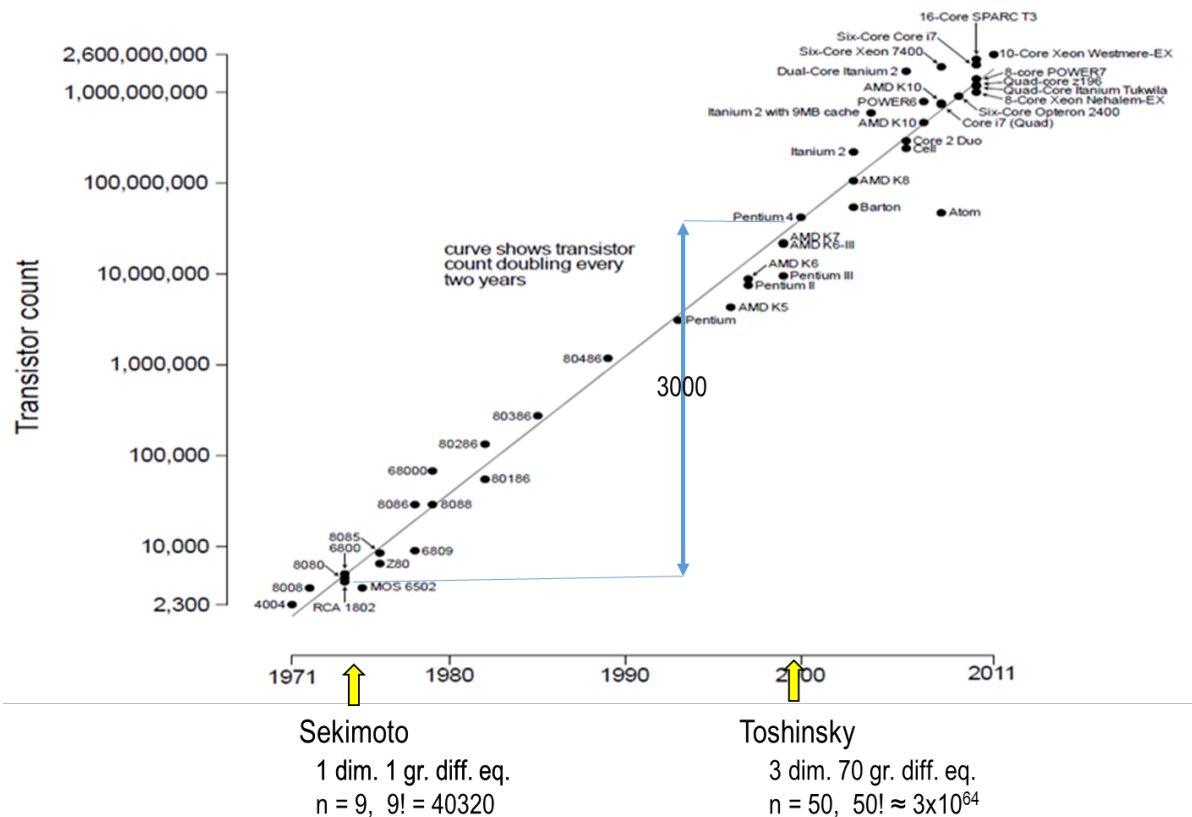


Figure 5. Increase of computer performance and problem size with year

3. Future Computation in Nuclear Engineering

3.1. Computation in Future Nuclear Engineering

The computer performance will continue to increase as mentioned in Section 2.4 in the future. Several innovative computers such as quantum computers[5] are expected to be put to practical use in the near future. It will be able to handle larger and more complicated systems faster and more accurately. In the future of nuclear power, the role of computation should increase more and more.

One case of the computation in future nuclear engineering is for a new field of innovative nuclear engineering under development. In another case, the development of the computer enables calculation that was impossible to date. Here in this paper an interesting example of computation is shown for each case: innovative nuclear reactors for the fast case and accident managements for the second case.

3.2. Computation for Innovative Nuclear Reactor System

The computation technique will be improved even for the basic problems of conventional reactors. However, developments of computation technique are considered much more for innovative reactors[6]. Some of the important innovative reactors are shown in table 2 with their unique characteristics.

Table 2. Several unique characteristics for some innovative nuclear reactors

reactor types	unique characteristics
Fast Reactor	hard neutron spectrum re-criticality accidents
High Temperature Gas Cooled Reactor	neutron self shielding for double heterogeneity depressurizing accident
Molten Salt Reactor	liquid fuel (FP flow, on-line reprocessing)
Accelerator Driven System	sub-criticality anisotropic neutron field hard neutron spectrum
Fusion Reactor Blanket	sub-criticality anisotropic neutron field hard neutron spectrum

Each reactor type in this table contains many different subtypes. The fast reactor has many options for different fuel: oxide, metal, nitride, et al., and for different coolants: sodium, lead (or lead bismuth), gas, et al. The high temperature gas cooled reactor has typical two options: block-type fuel reactor and pebble bed reactor. The molten salt reactor has two types: thermal thorium reactor and fast reactor. The accelerator driven system uses solid core or liquid core. The fusion reactor blanket has two options; simple tritium breeding blanket and complicated fusion-fission hybrid blanket. It has also many options for different plasma core design, and many subtypes of design like the fast reactor.

Many innovative reactors other than those listed in this table have been proposed.

The unique characteristics shown in table 2 are only those related to reactor physics. The FP flow for the molten salt reactor includes both delayed neutron precursor and high neutron absorbers like Xe-135. They affect greatly the reactor physics characteristics.

Proper computation method should be developed to treat these characteristics shown in table 2.

3.3. Computation for Accident management

Experiences of Fukushima-Daiichi accident provided a lot of suggestions for protecting and mitigating such a severe accident. Quick proper response to the accident is one of the most important requirements. The director of reactor has to know all details of the reactor and should make an appropriate judgment on what to do when problems arise. However, this ability has been greatly exceeding that of ordinary human beings. Furthermore, at the accident all of necessary data cannot be obtained in most cases, and human error easily occur. Mental stress of the director and operators become too strong.

Computer can make a more calm judgment as compared to humans. It can make a proper judgment instantaneously from a lot of information. In case of an accident it is conceivable that the computer makes a decision on behalf of human beings.

All of the reactor information must be given to the computer. In an accident, some information may be impossible to be given due to disconnection of the signal cable or some other reasons. We have to build a system so that this kind of thing does not happen, but even if it happens, the computer system must make appropriate judgments with available information.

Rapid judgment is inevitable though the problem is so large and complicated. The artificial intelligence (AI)[7] seems very efficient tool for this problem. The AI programs for games such as chess and go-game has been developed drastically for recent years. Some of the technology of game programs may be employed in our program.

To err is human, and the responsibility for a nuclear accident is too heavy for the humans. The author considers humans should not make such judgements. However, according to usual human rules, it may appear that there is a doubt about the judgment of the computer. In such a case, it may become necessary to make a system directed by humans that can communicate with the computer.

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