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PROPOSED GUIDELINES FOR ADVANCED RADIATION SHIELDING SAFETY EVALUATION TECHNIQUE BY MONTE CARLO METHODOLOGY

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ABSTRACT

Guidelines for radiation shielding evaluation by Monte Carlo method was designed and developed for practical radiation shielding for radioactive material transport casks. The guidelines consist of current technical advancement on estimating the dose equivalent rates around the surface of a transport cask. The guidelines have two unique features: one is that the procedure of the radiation shielding analyses is illustrated as flow charts, which can be used as check sheets to validate the analyses. By following the flow charts, the applicant can perform the radiation shielding analyses properly and the regulatory agency can check whether the analyses performed by the applicant are proper or not. The other is that the guidelines provide documentation of the details of results of benchmark analyses for transport casks by Monte Carlo method including measurements, modeling descriptions for the analyses, results of analyses and evaluation. The guidelines could be useful to validate the procedure and the results of radiation shielding analyses for transport casks.

INTRODUCTION

Accurately estimating the distribution of radiation dose equivalent rates around a spent fuel shipping cask is fundamental to the analysis for the safety of the cask and the reliability of its shielding design; if measured dose equivalent rates around a cask exceed the calculated values, a cask cannot contain its expected amount of spent fuels. The radiation shielding structure of the spent fuel transport cask is composed chiefly of the multi-layered structure for the radiation shielding. Neutron shielding may be thin in some parts of the cask such as the periphery of the trunnion, where some neutrons emitted from the source region stream outside of the cask.

The validity of the Monte Carlo method has been demonstrated in shielding analysis of a spent fuel transport cask. [1, 2] However, the Monte Carlo has not been yet employed as a means of the safety analysis. In spite of the restriction for geometrical expression, the two dimensional discrete ordinates Sn code, DOT3.5, [3] has been employed as a typical code for shielding analysis of the cask.

In order to comply with the request from the stakeholder of the transport cask industry, we intend to develop the guidelines for radiation shielding evaluation of transport casks by Monte Carlo method.

The guidelines consist of current technical status on estimating the dose equivalent rate around the surface of a transport cask, considerations in the safety evaluation and the current status of legal affairs for the purpose of applying the radiation shielding analyses based on Mote Carlo method. Furthermore, the guidelines are useful for both the applicant and regulatory agency relevant to the transport casks; the applicant for the transport casks can show to the regulatory agency the shielding ability of the transport casks designed based on the reasonable evaluation approach. The regulatory agency, on the other hand, can review the calculation in the written application in a proper manner and validate it. Additionally, the shielding designers of the radioactive material transport cask utilize the guidelines; they can design the transport cask more practically based on the adequate ways. The guidelines have two unique features: one is that the calculation process is illustrated, which can be used to calculate the radiation shielding properly. Another feature is that the shielding benchmarks calculations for transport casks by Monte Carlo method are attached, which is based on the previously performed dose rate measurements of the casks. By comparison between measurements and the calculations for the transport casks, accuracy level of the shielding calculation can be determined.

THE GUIDELINES FOR RADIATION SHIELDING EVALUATION OF TRANSPORT CASKS BY MONTE CARLO METHOD

Scope of the Guidelines

The guidelines are intended for the exclusive casks for transport or the dry metal casks for storage and transport of spent nuclear fuels. Specific recommendations are made regarding radiation attenuation calculations, shielding design and standards of documentation for the use of Monte Carlo method. The draft of the guidelines provides guidance to regulatory agency, electric companies, and architect-engineers who are responsible for the shielding design of radioactive transport casks. The draft does not consider sources of radiation other than those associated with radioactive transport casks. It also excludes considerations of economic aspects of shielding design other than the choice of analytical scheme based on Monte Carlo method. The document discusses methods of analysis and the shielding input data appropriate to Monte Carlo method.

The Organization of the Guidelines

On the purpose of the guidelines, valuable annexes are provided as follows:

1) Terms and definitions which are used for explanation of shielding calculation technique based on Monte Carlo method. Terms and definitions are provided to assure correct understanding of selected terms as they are used in the draft. A number of terms are used in the draft as defined in several textbooks on the subject of radiation shielding based on Monte Carlo method.
2) Shielding benchmark calculations for radiation penetration experiment with geometric configuration of the transport cask. This annex gives applications of Monte Carlo method, including the dry transport casks and wet transport casks problems.

Regulation Requirements

Radiation shielding performance of the transport casks with nuclear spent fuels must be maintained under the transport condition of the regulations for the safe transport of radioactive material. In the IAEA regulation of spent fuel transport packages with respect to shielding safety, the radiation level under normal transport shall not exceed 2.0mSv/h at any point on the external surface of the transport cask, and 0.1mSv/h at 2m from the external surface of the conveyance. [4] The radiation level under accident conditions of transport, on the other hand, shall not exceed 10mSv/h at 1m from the external surface of the transport cask. [4] Additionally, under Japanese

regulation, the radiation level under routine conditions of transport shall not exceed 0.1mSv/h at 1m from the external surface of the transport cask. The design of radiation shielding for transport casks is performed on the basis of this criterion.

The Shield Design for Casks

Following items are necessary to design transport casks for radiation shielding to meet the regulation [5]:

- specifications on radioactive contents,
- source intensity of radioactive contents,
- evaluation technique of radiation shielding, and
- criterion for the design of radiation shielding.

In the present study, all the computational process of the shielding calculation based on Monte Carlo method was classified into some processes, which is useful for assessing calculation. As a result, it was found that the following process is required to apply shielding calculation technique based on Monte Carlo method to transport casks:

a) modeling of geometric configuration,
b) approach in the use of the variance reduction techniques applicable to shielding configurations,
c) approach in the use of the estimator(tally) applicable to shielding configurations,
d) quality of random number generator for Monte Carlo method, and
e) evaluation of calculation result and statistics.

The Comprehensive Calculation Procedure

The ultimate goal of this study is to illustrate the comprehensive calculation procedure, which helps us to perform the calculation properly. The calculation processes which are divided into five categories in the foregoing section are illustrated by Figure 1-5. These flow charts are the essence of the guidelines (draft). Especially, these flow charts consist of the quality of random number generator for Monte Carlo method and the evaluation of the calculation result and statistics. We revisit the evaluation of the result and statistics in more detail, next section. By the following these process, the applicant can perform the radiation shielding calculation properly and the regulatory agency can check whether the calculation performed by the applicant is proper or not.

Geometric configuration of the transport cask which is used for the Monte Carlo calculation is not very particular to the other calculation techniques. For more detail modeling, homogenization of region or treatment of dimension is taken with caution. Meanwhile, the setting of variance reduction and the choice of the estimator are peculiar to the Monte Carlo calculation.

The important statistic generated by the calculation is the “figure of merit.” This is defined as follows:

$$\mathrm{FOM} \equiv \frac{1}{R^2 T} \tag{1}$$

where T is the simulation time, which is proportional to the number of histories run, and R is the relative error. For different simulations of the same problem, the simulation with the largest FOM is preferred since it requires the least time or produces a specified relative error.

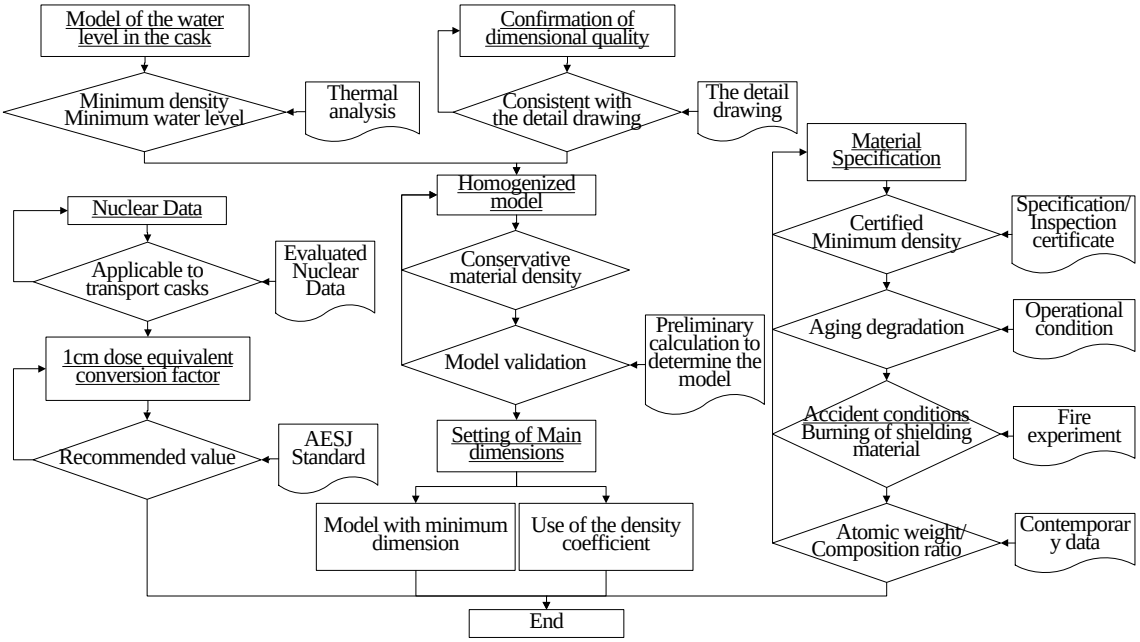
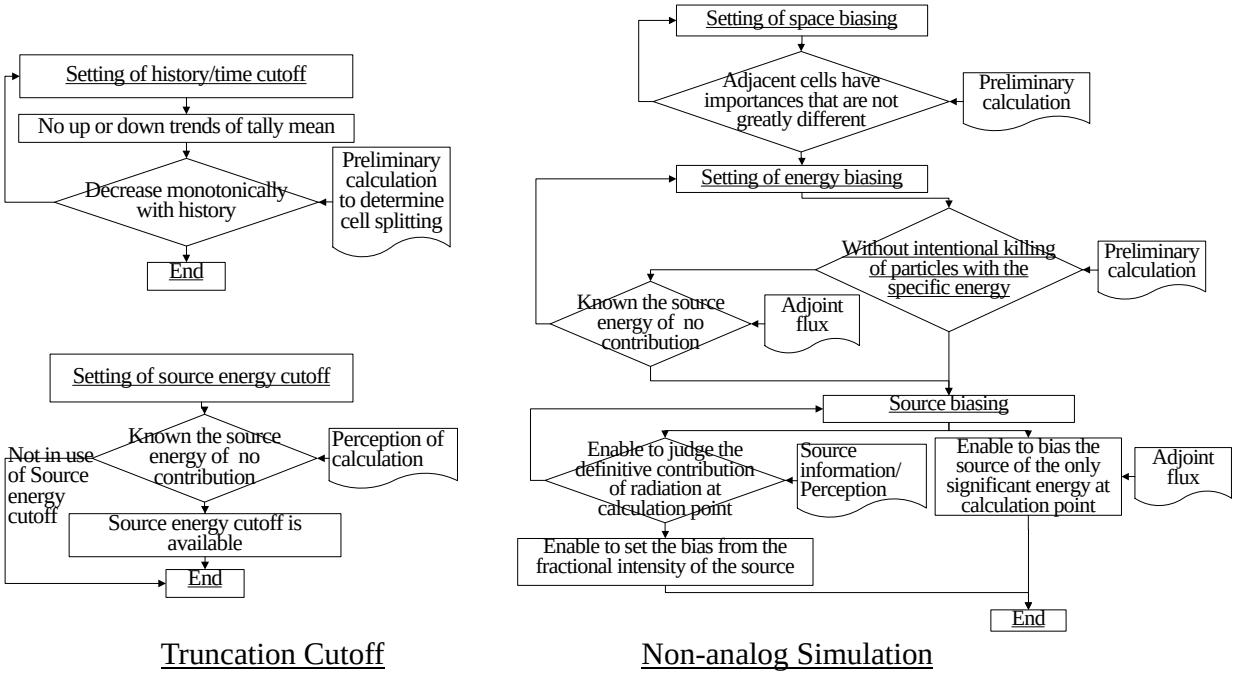


Figure 1.Modeling of geometric configuration of transport casks



Truncation Cutoff Non-analog Simulation

Figure 2.Approach in the use of the variance reduction techniques applicable to shielding configurations of transport casks

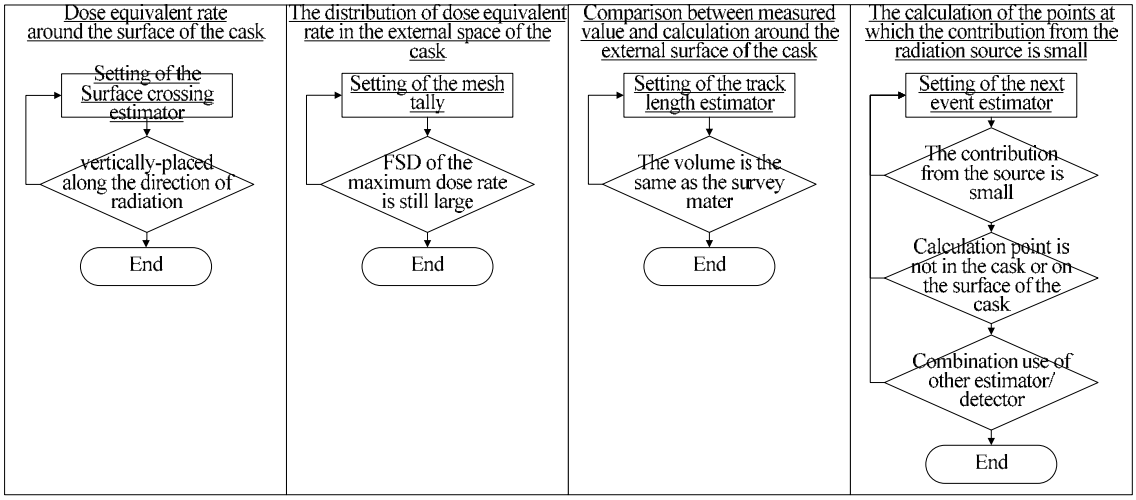


Figure 3.Approach in the use of the estimator (tally) applicable to shielding configurations of transport casks

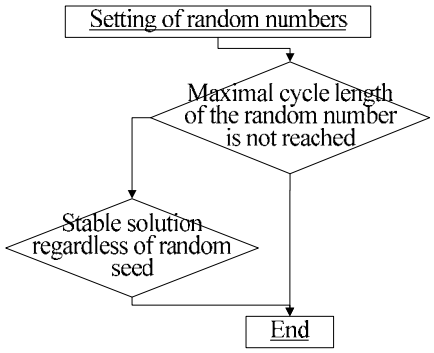


Figure 4.Approach in the quality of random number generator for Monte Carlo method

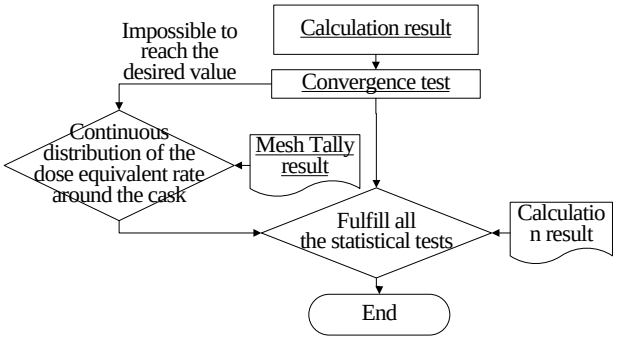


Figure 5.Approach in the evaluation of the calculation result and statistics

Accuracy and Precision of Calculation Results

With Monte Carlo method and its various variance reduction techniques, it is possible to produce calculation results that, while very precise, are not very accurate. Technically, precision is the uncertainty in the tally mean caused by the statistical fluctuations in the individual scores of the simulated histories. [6] By contrast, accuracy is a measure of how close the tally mean is to the true physical quantity being estimated. [6] The difference between the true value and the expectation

value of the simulation tally is called the systematic error, an important quantity but one that is seldom known.

Nuclear data and geometric configuration, which was used to perform the radiation shielding calculation, should be accurate for the high integrity evaluation. On the premise of this, the statistical checks with the calculation should pass the provisional standard with which various calculation codes are specified. The existence of the benchmark experiments which are applicable to the condition of the source intensity, the geometric configuration and material components enables the validation by the calculation based on Monte Carlo method. For this, the guidelines include the shielding benchmark calculations.

In many cases, however, there are not enough experiments which are performed by same configuration to which we want to calculate. In order to determine statistical validity of the calculation result, the statistical check which is served with output has to be passed, that is to say, the calculation has high accuracy.

Meanwhile, the accuracy of calculation should be evaluated by the result of benchmark experiment. However, for the determination of the accuracy of the result, following evaluation can be substitute for the result of benchmark experiment:

1) The dose equivalent rate is distributed continuously around the cask;
2) Same result is available regardless of the different use of biasing method.

CONCLUSION

In the present study, the guidelines for radiation shielding evaluation of transport casks by Monte Carlo method are established. In this document, specific recommendations are made regarding radiation attenuation calculations, shielding design and standards of documentation. The guidelines are expected to be used for the confirmation that effective shielding calculation has been performed and the result is verified.

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