NUMERICAL EFFECTS IN THE NEUTRON FLUX CALCULATIONS INTO WWER-TYPE REACTOR VESSELS BY MONTE CARLO METHOD

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ABSTRACT

The calculation of neutron fluxes and fluence into reactor pressure vessel is a regulatory requirement in the stages of the design, operation and plan lifetime extension. The reactor vessel is considered a unique and non-substitutable part of the NPP that undergoes degradation. The main source of the aging comes from the fast neutron damage induced in the steel crystalline lattice. Due to the proximity of the core edge to the vessel inner surface; the vessel steel is exposed to high fast neutron fluence. The effect of this irradiation on the mechanical properties becomes more acute because of the impurities measured in the Russian steel alloys. In the present paper, a PC version of the Monte Carlo 3-D HEXANN-EVALU system is used for the estimation of the WWER reactor pressure vessel irradiation. It was selected on the basis of its flexible options that on the other hand need to be quantified in connection with the desired magnitudes. The parameters that control the random walk of neutrons as well as the efficiency increasing options included in the code are studied in order to identify their impact in the final results for fluxes and fluence in the reactor pressure vessel. As a result an optimal set of parameters is suggested.

INTRODUCTION

The use of Monte Carlo techniques for nuclear reactor calculations is an extended practice for the solution of diverse problems and the simulation of physical processes. In any case, some insight and understanding of the techniques applied is essential. The external parameters inherent to the used code that are detrimental to the calculations, must be specified by the user, while the inappropriate setting of such parameters may lead to highly inefficient calculations and maybe even to erroneous results.

Many of the Monte Carlo method features are easy to understand intuitively but sometimes difficult to prove in a rigorous way. By the other hand the understanding of the limitations and advantages of the method are relevant to the solution of a given problem.

In the current paper the HEXANN-EVALU Monte Carlo code [1] is applied for the evaluation of the neutron fluence to the stainless steel vessel of a WWER-440 reactor, but the main efforts are devoted to the selection of a set of several input parameters connected to the reduction variance techniques as well as to the improving of the code efficiency. Several specific studies were performed in order to get a better insight in the calculation scheme details and the optimal way of using the code more efficiently.

BACKGROUND

Several studies were performed in connection with the determination of the fast neutron fluence to the reactor vessel. The aim of that work was the completion of the Safety Report for Cuban Juragua NPP. The results of those studies are reported in [2]. At that time the special options of the code devoted to the variance reduction techniques were not widely analyzed. Because of the lack of experience in using the variance reduction techniques, the aim of the paper was devoted to the numerical studies related to their use.

THE HEXANN-EVALU CODE FOR PWR PRESSURE VESSEL IRRADIATION CALCULATION

The code combination is intended to calculate neutron currents and reaction rates surrounding the core of a WWER type reactor. The neutrons are started from the outermost hexagon faces and the simulation goes over all the area outside the core.

The program HEXANN performs the Monte Carlo simulation and creates a file (called history tapes) that contains the neutron histories. The history tape is to be evaluated by the program EVALU in order to obtain current and reaction rate estimated at presigned sites.

Hexagonal cassettes make up the zone in which calculations are performed, the structural elements are either included into hexagons of the same size as the core elements or forming concentrical cylinders. One can suppose that the whole system exhibits a 30-degree symmetry and the Monte Carlo simulation is performed in a 30-degree radial sector with reflecting boundary conditions.

The spatial domain of the simulation is assumed to be filled with a nonmultiplying medium and no upscattering is allowed in the collision process. The energy degradation is taken into account in a multigroup way; the cross sections are input in a library. Anisotropy scattering up to P3 is considered.

The cross sections used for the calculations were obtained on the basis of the microscopic library L26P3S34 [3].

This library uses the fixed format from ANISN, with a 26-group structure, the polynomial expansion order for the dispersion description is P3 and includes 34 different materials. Using the ANISN code the mixture tables are prepared for the calculation of the macroscopic cross sections of the regions surrounding the core. The calculations were performed for the first thirteen groups from the library with energies between 14.92 and 0.111 Mev.

The spectrum for the reactor emerging neutrons (fission + dispersion) and the neutron fraction for the fine groups structure is obtained from the spectral calculations with WIMS/D4. The 69- group structure from WIMS/D4 was coupled with the 13- group structure of L26P3S34. The spectrum for groups with energies above 10 Mev is obtained by extrapolation.

The data for the calculation of the emergent neutron source was taken from the results from the three-dimensional reactor simulator SPPS-1, that is a three dimensional diffusion code in hexagonal geometry in a coarse mesh scheme and using the finite difference method [4].

The code includes techniques for increasing efficiency such as survival biasing, splitting and Russian roulette as well as path stretching with a special correction included. More detailed description of the code may be seen from the literature [1].

EFFICIENCY AND REDUCTION VARIANCE TECHNIQUES, SPLITTING, AND RUSSIAN ROULETTE

Several studies were performed in connection with the selection of the optimal parameters to the aim of increasing the efficiency achieving a minimization of the statistical error. Using a number of starters which ranges from 250,000 to 2,000,000 the FOM (figure of merit factor) was calculated, leading to the conclusion that the best number of starters for this kind of calculations was 1,75 million. The performing of the calculation implied the changing of the maximum number of starters allowed inside the code.

For the evaluation in all cases, and on the basis of a previous numerical study, it was selected as estimator the collision estimator.

According to [5], the quality of a Monte Carlo simulation may be judged on the basis of the following factors:

Precision, it means the degree of deviation of the sample mean.

Efficiency/reliability (FOM=$1/R^2T$), where R^2 is the standard deviation and T is the time used for the evaluation.

Accuracy, it means the degree of deviation of the true mean.

Given as satisfactory the achieved accuracy, on the basis of the former studies [5] for the vessel fluence calculations, we have concentrated all the efforts in looking for a higher precision and efficiency.

In Table 1 and Figs. 1 and 2 the results for the selection of the number of starters are shown.

TABLE 1

STARTERS	250 000	500 000	750 000	1M	1.25M	1.5M	1.75M	2M
DELTA(%)	**12.24**	**8.40**	**7.24**	**6.17**	**5.31**	**4.93**	**4.70**	**4.36**
T(min, EVALU)	**1.86**	**3.57**	**5.05**	**6.26**	**8.86**	**10.36**	**11.18**	**21.35**
T(min, HEXANN)	**1.42**	**2.79**	**4.05**	**4.8**	**6.33**	**7.81**	**8.83**	**12.23**
T (total)	**3.28**	**6.36**	**9.1**	**11.06**	**15.19**	**18.17**	**20.01**	**33.58**

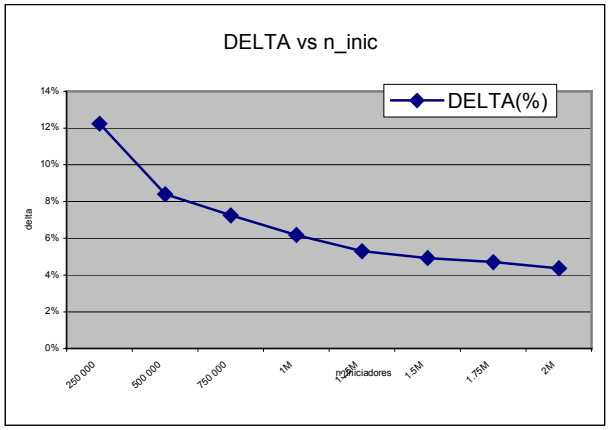

FIGURE 1. FOM vs. starters number

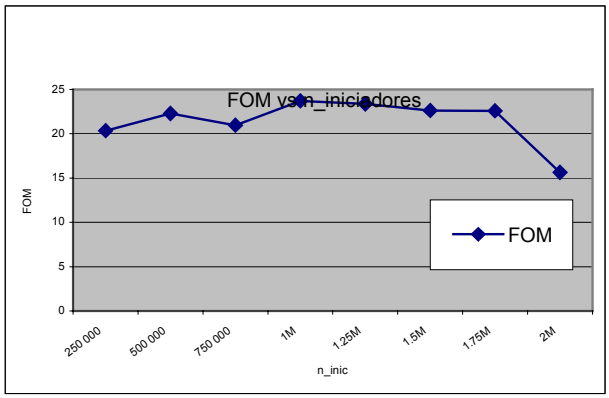

FIGURE 2. Precision vs. starters number

The simultaneous presence of particles with very different weights drives to an increase in the variance of the estimated quantities. Additionally particles with very low weight do not contribute to the final result but increase the computing time without any additional benefit.

The main objective of the introduction of the Russian roulette and splitting procedures is to level in any region the weights of the different particles.

In the code users manual the values for splitting weights were recommended between 2,0 and 3,0 times the standard weight, while the Russian roulette weights range between 0,1 and 0,3 times the standard values.

Studies for the selection of the optimal splitting weights were carried out being fixed the Russian roulette parameter, and equal to 0,2 times the standard weight. In a similar way the optimal Russian roulette weight was investigated using a constant splitting weight of 3,0 times the standard weight.

The obtained results are shown in Tables from 2 to 5 and Figs. From 3 to 6.

TABLE 2

WSPL	2	2.25	2.5	2.75	3
DELTA (%)	**4.08**	**4.2**	**4.47**	**4.6**	**4.7**
T_HEX (Min)	**9.87**	**9.58**	**8.98**	**8.4**	**8.4**
T_EVA (Min)	**14.1**	**11.9**	**11.04**	**10.8**	**11.8**
T total	**23.9**	**21.5**	**20.02**	**19.2**	**20.2**

TABLE 3

WSPL	2	2.25	2.5	2.75	3
FOM	**0.039**	**0.039**	**0.039**	**0.041**	**0.045**

TABLE 4

9WRR	0.1	0.2	0.25	0.3
DELTA (%)	**4.4**	**4.70**	**4.66**	**4.5**
T_HEX (min)	**11.4**	**10.26**	**9.55**	**8.4**
T_EVA (min)	**13.7**	**11.93**	**11.38**	**11.3**
T_total	**25.1**	**22.19**	**20.93**	**19.6**

TABLE 5

WRR	0.1	0.2	0.25	0.3
FOM	**20.06**	**20.38**	**21.98**	**25.26**

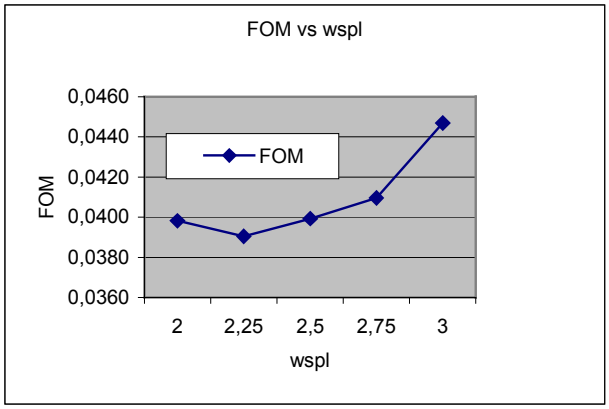

FIGURE 3. Precision vs. WSLP

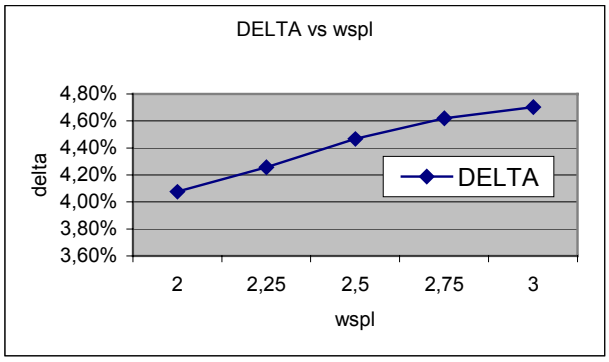

FIGURE 4. Efficiency vs. WSLP

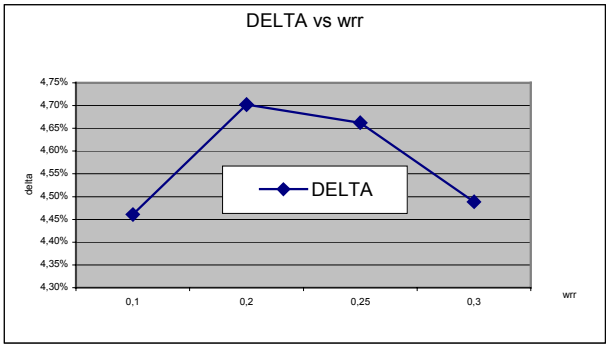

FIGURE 5. Precision vs. WRR

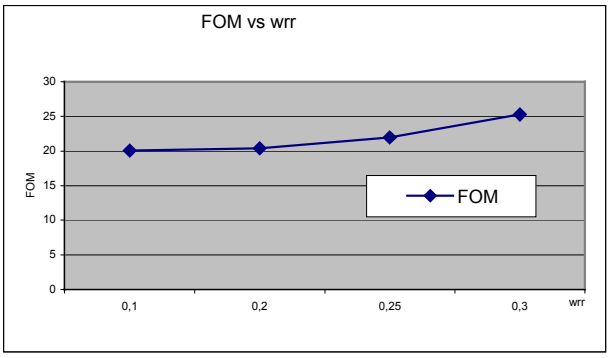

FIGURE 6. Efficiency vs. WRR

REGION WISE IMPORTANCE AND PATH STRETCHING

The ratio of the statistical weight of a starter to that of a typical particle in the region is called the region wise importance. The HEXANN-EVALU allows both options, it means the input of a set of quasioptimum region wise importance and the automatic corrected region wise importances use.

Region importances are used in order to increase the number of particle histories in a way that the deepest

Regions achieve a good statistics for the simulation of the process.

The use of path stretching option and the selection of a quasioptimum importance set requires additionally the determination of the parameter b and s.

Parameter s is tightly related to the exponential behavior of the quasioptimum importance, while b is called the path stretching.

Parameter used in deep penetration problems being forced the particles toward a particular.

Region through the changing of the free flight length.

According to the suggestions of the HEXANN-EVALU users manual, it was performed a run for the optimal parameters determination, it means.

Using 10000 initiators and the automatic importance option implemented every 1000 batches.

The following values were obtained:

For $\Sigma_t = 0{,}3412$,

$\Sigma_S / \Sigma_t = 0{,}818$,

And $\alpha = 0.7902$

From these values s is obtained as

$$s = \Sigma_t \sqrt{3}*(1-\Sigma_s/\Sigma_t) = 0{,}25.$$

And for maximum path stretching parameter

$$b_m = s*\alpha/\Sigma_t = 0{,}5788.$$

Knowing that the optimum is near to $0{,}8* b_m$ we finally obtain b=0,463.

Once determined these parameters we realize that the obtained value for s is overestimated at least in a 33 % if we compare its value with the obtained by the code authors [1]. The impact of this result on the calculated importances is very high giving an overestimation of those quasioptimum importances mainly in the regions allocated far away from the reactor core.

The obtained importances do not match the behavior of the automatic importances given by the program. Because of this behavior, a more detailed study of the proposed importances has to be done in the near future.

The obtained result for α, in our case shows a very similar value to the one obtained by the program authors, but because of the Differences in s and Σ_t, we got a 15% overestimated value for b= 0,463.

RECOMMENDATIONS AND CONCLUSIONS

a) It is necessary to improve the value for s mainly through an overall analysis of the library that may be the cause of the high overestimation for Σ_t.

b) A deterministic calculation should be performed with a discrete ordinates code.

c) Also to do a detailed study for the matching or not of the automatic importances and the quasioptimum ones per region, knowing in advance the different approach used for the determination of each kind of importances.

d) To use and study the low energy Russians roulette option, implemented in the code and no tested up to now.

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