Calculation of the Decommissioning Radiation Field of Nuclear Power Plants Based on the Coupling of MC and Point Kernel Integration

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Introduction

- In the three-dimensional simulation system for the decommissioning of nuclear power plants, the radiation field level of the decommissioning site needs to be displayed in **real time** with the decontamination and demolition of the nuclear facilities.

Figure 1.1 Visual display of 3D radiation field

- It requires the radiation field calculation module to calculate the radiation field level **quickly** and **accurately**.
- **Space problem**: geometrically simple regions and geometrically complex regions both exist in in the decommissioning site.
- The three basic methods of radiation field calculation can not solve the problem and then can not meet the requirements of calculation speed and accuracy.
- The **MC-PK coupling method** is proposed.

Table 1.1 The adv. and disad. of three basic methods

Methods	Discrete ordinate (S_N)	Point kernel integration (PK)	Monte Carlo (MC)
Applicable region	Simple	Simple	Complex
Calculation time	Long	Short	Long
Accuracy	High	Low	High

MC-PK Coupling Method

- Basic idea:
  - To use MC in geometrically complex regions;
  - To use PK in geometrically simple regions;
  - To transform particle parameters on the coupling surface.

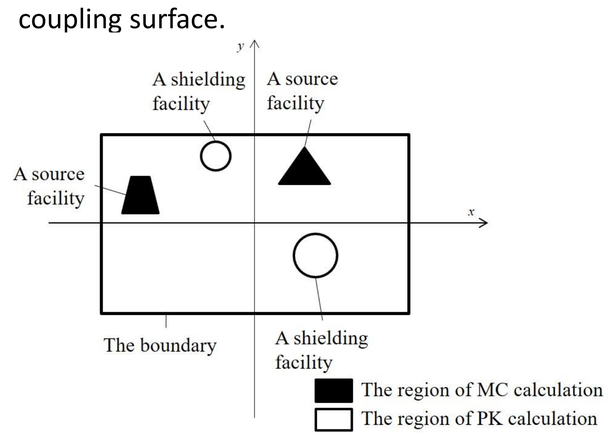

Figure 2.1 Decommissioning site division of a nuclear power plant

- Assuming that the MC region is a pure emitter, it can be derived from the Boltzmann equation:

$$j_n^+(\boldsymbol{r}_s, E, \boldsymbol{\Omega}) = S_A(\boldsymbol{r}_s, E, \boldsymbol{\Omega})$$

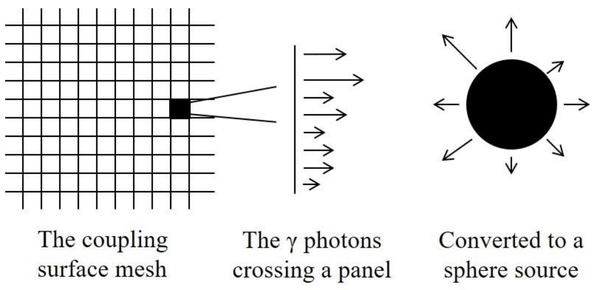

Figure 2.2 A source on the coupling surface is converted into a sphere source (the length of the arrow in the figure is proportional to the γ energy)

Single Source Calculation Model

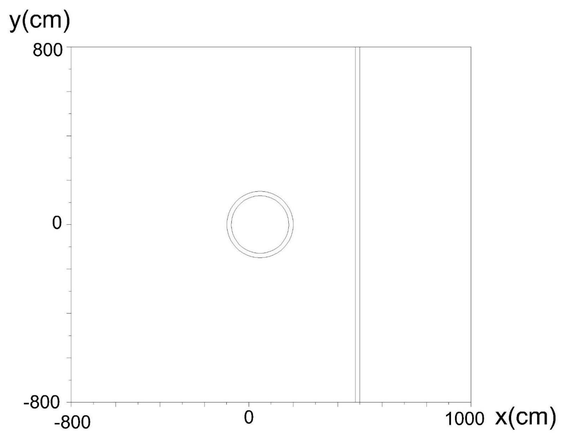

Figure 3.1 Single source calculation model (0.662MeV, 1.0E6Bq)

Table 3.1 Result comparison of the coupling method and MC method in the single source model

	γ energy flux rates (MeV/(cm²•s))		Ratios
Point	Coupling method	MCNP5	
1	4.6630E-03	1.4678E-03	3.177
2	3.5499E-03	1.1497E-03	3.088
3	8.3030E-04	2.9278E-04	2.836
4	6.4362E-03	2.0831E-03	3.090
5	2.2223E-03	6.3462E-04	3.502
6	4.5223E-03	1.2367E-03	3.657
7	2.8517E-03	7.2289E-04	3.945
8	2.0303E-03	4.9189E-04	4.128
9	3.8058E-03	9.6218E-04	3.955
10	3.1389E-03	7.3675E-04	4.260

- F_{MC-PK}/F_{MC} = 3-5
- Calculation time(CPU: 2.9GHz Memory: 2GB)
  - MCNP5: 4h
  - MC-PK: 30min + 40min

Table 3.2 Calculation accuracy of the coupling method for different photon energies in the single source model

	F_{MC-PK}/F_{MC}			
Point	0.662MeV	0.83MeV	1.17MeV	1.33MeV
1	3.177	2.509	1.792	1.847
2	3.088	2.857	1.947	1.879
3	2.836	2.667	1.913	1.964
4	3.090	2.885	2.017	1.948
5	3.502	3.247	2.270	2.168
6	3.657	3.229	2.232	2.137
7	3.945	3.464	2.326	2.279
8	4.128	3.685	2.534	2.370
9	3.955	3.556	2.441	2.298
10	4.260	3.726	2.524	2.396

Table 3.3 Calculation accuracy of the coupling method for different shield thicknesses in the single source model

	F_{MC-PK}/F_{MC}		
Point	5cm	20cm	40cm
1	2.521	3.177	5.362
2	2.712	3.088	2.765
3	3.268	2.836	0.897
4	2.672	3.090	3.821
5	3.137	3.502	3.017
6	2.939	3.657	4.106
7	3.176	3.945	3.932
8	3.351	4.128	4.023
9	3.139	3.955	4.709
10	3.245	4.260	4.912

Table 3.4 Calculation accuracy of the coupling method for different grid numbers in the single source model

	F_{MC-PK}/F_{MC}	
Point	① G: 32 A & R: 2.5cm	② G: 64 A &R: 1cm
1	3.177	3.178
2	3.088	3.088
3	2.836	2.837
4	3.090	3.091
5	3.502	3.503
6	3.657	3.658
7	3.945	3.946
8	4.128	4.129
9	3.955	3.956
10	4.260	4.262

Table 3.5 Calculation accuracy of the coupling method for different energy group spacings in the single source model

	F_{MC-PK}/F_{MC}	
Point	0.2MeV	0.05MeV
1	3.177	2.968
2	3.088	2.877
3	2.836	2.600
4	3.090	2.913
5	3.502	3.260
6	3.657	3.443
7	3.945	3.696
8	4.128	3.855
9	3.955	3.731
10	4.260	4.014

- γ energy↑ accuracy↑
- Grid number↑ calculation time↑
- MC-PK coupling method has good stability.

Calculation of Qinshan Ⅰ

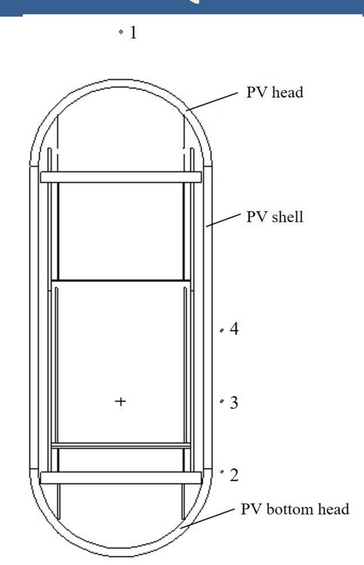

Figure 4.1 The simplified model of Qinshan I

Table 4.1 Result comparison of the coupling method and MC method in Qinshan I

	Air-absorbed dose rates (mSv/h)		Ratios
Point	Coupling method	MCNP5	
1	4.3988E+02	7.3010E+01	6.02
2	4.1344E+03	2.7059E+03	1.53
3	6.3208E+03	6.4018E+03	0.99
4	4.1344E+03	6.5739E+03	0.63

- D_{MC-PK}/D_{MC} < 7
- Calculation time (CPU: 4.6GHz Memory: 64GB)
  - MCNP5: 8h
  - MC-PK: 1h + 5min

Conclusions

- The coupling method has reasonable accuracy, short calculation time and good stability.
- The MC-PK coupling method is adequate for the requirements of radiation field calculation in decommissioning of nuclear power plants.

Contact

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