# Secondary Gamma-ray Skyshine From 14MeV Neutron Source Facility(OKTAVIAN)

## -Comparison of Measurement with its Simulation-

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Abstract

Measurement of secondary gamma-ray skyshine was performed at the Intense 14MeV Neutron Source Facility (OKTAVIAN) of Osaka University with NaI and Hp-Ge detectors. From the result of measurements, some mechanism of secondary gamma-ray skyshine from 14MeV neutron source facility was found out. The analysis of the measured result were carried out with MCNP-4B for four nuclear data files of JENDL-3.2, JENDL-F.F., FENDL-2, and ENDF/B-Ⅵ. It was confirmed that all the nuclear data are fairly reliable for calculations of secondary gamma-ray skyshine.

## 1. Introduction

Evaluation of skyshine effect of radiation is important for estimating dose equivalent near nuclear facilities. Especially for a neutron source facility, though it was thought that contribution of neutron was dominant on skyshine dose, recently H.W.Kugel et al.[1] at TFTR found that dose equivalent due to secondary gamma-ray skyshine was as large as that of neutron at distances below 200m from the facility. We think from this result that direct gamma-rays from the facility play an important role as the skyshine effect. This suggests that it is very important to take into account the facility building configuration in dose-equivalent evaluation around the facility. It means therefore that experimental approaches are quite important as well as their analysis.

Generally, the word ‘Skyshine effect’ is a phenomenon that leakage radiation from the facility shines on the ground due to scattering or nuclear reaction with oxygen and nitrogen atoms in the upper air. However in this study, the skyshine effect includes all the contributions from the facility (direct contribution), from the ground (groundshine contribution) as well as from the upper air (real skyshine) ,because in a nuclear facility design we have to evaluate the dose-equivalent containing all possible contributions. Each contribution of the skyshine effect is schematically described in Fig.1.

In the Intense 14MeV Neutron Source Facility OKTAVIAN of Osaka University, investigation of the mechanism for secondary gamma-ray skyshine has been proceeded to propose semi-empirical expression of dose equivalent for each contribution above as a function of distance from the facility. With Hp-Ge detector, high energy-resolution gamma-ray spectra were measured and used to investigate the skyshine mechanism through identification of nuclear reaction. On the other hand, with NaI detector gamma-ray spectra were measured for evaluation of dose equivalents as a function of the distance from the facility. In this paper, the abstract of the mechanism we found out[2~4] was briefly described. Preliminary calculated results of dose equivalents with MCNP-4B performed using several nuclear data files were presented.

## 2. Experiment

Secondary $\gamma$-rays have been measured around the OKTAVIAN facility with an large Hp-Ge (180cc) detector and an NaI(Tl) scintillation detector (5 inch $\phi$ by 5 inch long).[4] The intensity of the neutron source is about $10^9$ neutrons/sec. Measurements were done at 24m, 43m, 100m, and 150m from the facility for NaI, while 31m, 55m, 88m, and 165m for Hp-Ge detector. In this study, to measure each contribution in Fig.1, we used bare-detector (total contribution) and shielded detector (real skyshine contribution and groundshine contribution). Every measurement was performed at a point which can directly view the facility. To measure 'real skyshine contribution' and 'groundshine contribution, the detectors were shielded with some lead block and 1mm-thick cadmium sheet as described in Figs.2 and 3. The lead block was employed to eliminate gamma-rays which come from directions we don't need. The cadmium sheet was used to suppress neutron capture reaction in the lead shield.

To evaluate the dose equivalent originating from the skyshine gamma-ray, we performed unfolding of the spectra measured with the NaI detector. The response function of the detector was calculated with the Monte Carlo method. Unfolding code FERDO was used to estimate the gamma-ray spectra at the detector. The dose equivalent was obtained with the measured gamma-ray spectra and the flux-to-dose conversion factor.

## 3. Results and discussion

Figure 4 shows the obtained spectra measured with the Hp-Ge detector. All the foreground(on-beam) spectra (①,②and③in the figure) are distinctly different from the background(off-beam) spectrum (④in the figure) in high energy region above 3 MeV. Many discrete gamma-ray peaks were observed in the 'total contribution'. Also in the 'groundshine contribution', discrete peaks of hydrogen and silicon capture gamma-rays were observed. However in the 'real skyshine contribution', there is no discrete peaks in high energy region. These spectra enabled us to propose some mechanism of secondary gamma-ray skyshine as shown in Fig.5. As for the 'real skyshine' spectrum, Compton scattered gamma-rays produced in the air are dominant in the 'Real skyshine contribution', because the reaction cross section of $^{16}O(n,\gamma)$ and $^{14}N(n,\gamma)$ for thermal neutrons are exceptionally small as shown in Table 1. Consequently, significant peaks were not observed. Also in the 'Groundshine contribution', Compton scattered gamma-rays generated in soil and discrete secondary gamma-rays produced by $(n,\gamma)$ reactions of hydrogen and silicone existing in soil are dominant. Almost all discrete peaks in the total contribution are generated in the shielding wall of the facility, because few peaks exist in the real skyshine and groundshine spectra. Their nuclear reactions were identified by ascertaining the emitted gamma-ray energies. The result is shown in Table 1 and Fig.4. It is confirmed that all the nuclides corresponding to the nuclear reactions are contained in the shield wall, and gamma-ray produced with $(n,\gamma)$ reactions induced by slowing down neutrons in the wall are dominant.

Dose equivalents around the facility obtained by the NaI detector are shown in Fig.6 together with the calculation. The calculation was performed with MCNP-4B assuming that the shape of the OKTAVIAN facility is a co-axial cylinder as shown in Fig.7. The ring detector was employed to evaluate the gamma-ray spectra considering the statistical accuracy. The measured dose equivalents were in good agreement with the calculated values using JENDL-3.2, JENDL-F.F., FENDL-2, and ENDF/B-Ⅵ. The calculated values with ENDF/B-Ⅵ and FENDL-2 show a slightly smaller than other nuclear data. However, the nuclear data are fairly reliable for calculations of secondary gamma-ray skyshine. Fig.8 shows the energy differential dose equivalent at 60m from the facility calculated with MCNP-4B using the nuclear data of JENDL-3.2, JENDL-F.F., FENDL-2, and ENDF/B-Ⅵ. The spectrum calculated with ENDF/B-Ⅵ has larger discrete peaks than the results by other nuclear data, because the secondary gamma-ray spectrum in ENDF/B-Ⅵ includes some significant discrete peaks. The spectrum for ENDF/B-Ⅵ in Fig.8 shows lower than the others in high energy region. This tendency is observed in all the calculated cases for distances of 40m to 200m. We think that this is one of the reason why the calculated dose equivalent spectrum using ENDF/B-Ⅵ shows smaller than others.

The 'n-value' in a function $1/r^n$ which is approximately evaluated as an attenuation curve of gamma-ray skyshine, where r is the distance from the facility. This equation is available within several hundreds meters from the facility.[3] In the present study, using the integral counts above 3MeV in the Hp-Ge spectra for several distances from the facility, the 'n-values' are evaluated for 'total', 'real skyshine', and ‘groundshine’ contributions. Also MCNP-4B calculations were carried out to obtain ‘n-values’ for JENDL-3.2. The results are shown in Table 2. The ‘n-value’ of ‘Real skyshine’ contribution is slightly smaller than those of ‘Total contribution’ and ‘Groundshine contribution’. Table 2 shows an excellent agreement between the experimental and calculated ‘n-values’. Consequently, the dose equivalents decay on the attenuation curve $1/r^n$ where n=1.6～2.1. These data are approximately interpreted as decay phenomenon of a point source; n=2. It is thought that the reason why the ‘n-value’ of real skyshine is lower than 2 is that the atmosphere, i.e., gamma-ray source region in which Compton scattering occurs becomes a volume source.

## 4. Conclusion

Measurements of secondary gamma-ray skyshine with NaI and Hp-Ge detectors had been carried out around the OKTAVIAN facility of Osaka University. From the result of measurements with Hp-Ge detector, the on-beam spectrum had a structure distinctly different from the off-beam spectrum above 3MeV. The mechanism of secondary gamma-ray skyshine was discussed with three measurements including real skyshine, groundshine, and total contributions. It was found that the contribution of direct gamma-rays from the facility was large and important in dose equivalent evaluation.

Moreover as for n-value in the attenuation curve ($1/r^n$) of dose equivalent, an excellent agreement was obtained between the experiment and calculation. It was found that all the nuclear data used for the analysis are reliable for calculations of secondary gamma-ray skyshine. Also dose equivalents around the facility were measured with NaI detector. The analysis was carried out using MCNP-4B with JENDL-3.2,JENDL-F.F.,FENDL-2,ENDF/B-Ⅵ. As a result, the measured dose equivalents were in good agreement with the calculated values.

In the next step, it is planning to carry out experiments at YAYOI Reactor (fast neutron source of Univ. of Tokyo) and UTR-KINKI (thermal neutron source of Kinki Univ.), in order to study the relation between initial neutron energy and decrease of dose equivalent as a function of distance from the facility.

## Acknowledgement

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## References

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Table 1 Reaction cross section of main nuclides existing in and around the facility

| Nuclides | Reaction cross section (n, γ) | Reaction cross section (n,n'γ) | Total contribution | Real skyshine | Groundshine |
|---|---|---|---|---|---|
| H | 0.29 | − | Observed | Not observed | Observed |
| N−14 | 6.60E−02 | 0.4 | Observed | Not observed | Not observed |
| O−16 | 1.70E−04 | 0.51 | Observed | Not observed | Not observed |
| Si−nat | 0.15 | 0.43 | Observed | Not observed | Observed |
| Ca−nat | 0.39 | 0.27 | Not observed | Not observed | Not observed |
| Al−27 | 0.2 | 0.43 | Not observed | Not observed | Not observed |
| Fe−56 | 2.24 | 0.73 | Observed | Not observed | Not observed |
| Cl−nat | 29.4 | 0.35 | Observed | Not observed | Not observed |

Table 2 Comparison of 'n-values' in a gamma-ray attenuation function $1/r^n$ calculated with MCNP-4B and the measured results with Hp-Ge detector

| | Total contribution | Real skyshine contribution | Groubdshine contribution |
|---|---|---|---|
| Experiment | 2.1 ± 0.3 | 1.6 ± 0.2 | (2.0 ± 0.5) |
| Calculation | 1.97 ± 0.02 | 1.78 ± 0.09 | 2.1 ± 0.2 |

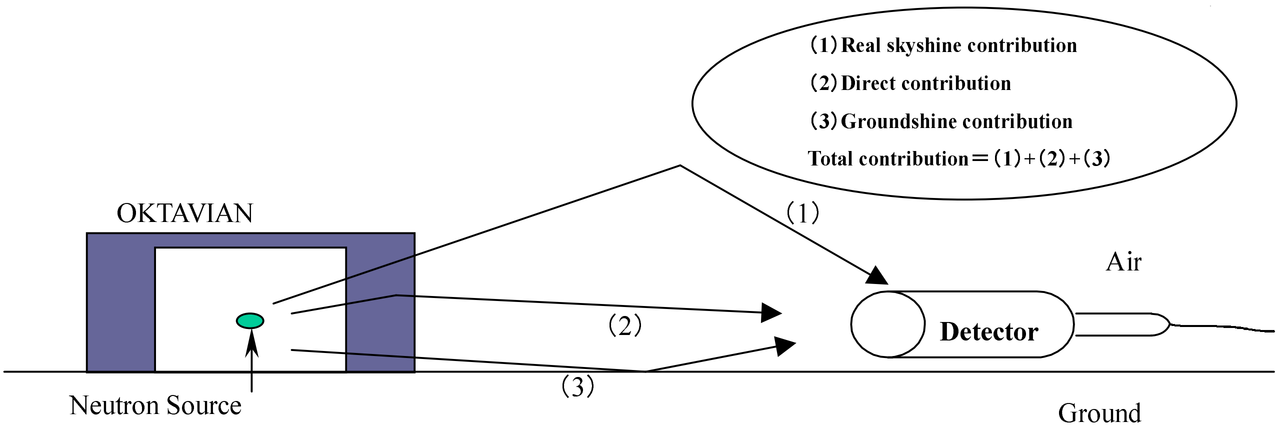


Fig.1 Schematic description of secondary gamma-ray skyshine effect

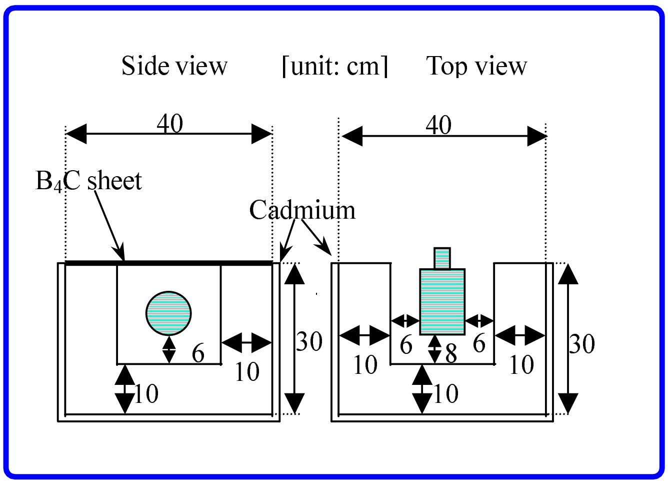


Fig.2 Ge detector arrangement for measurement of 'Real skyshine'

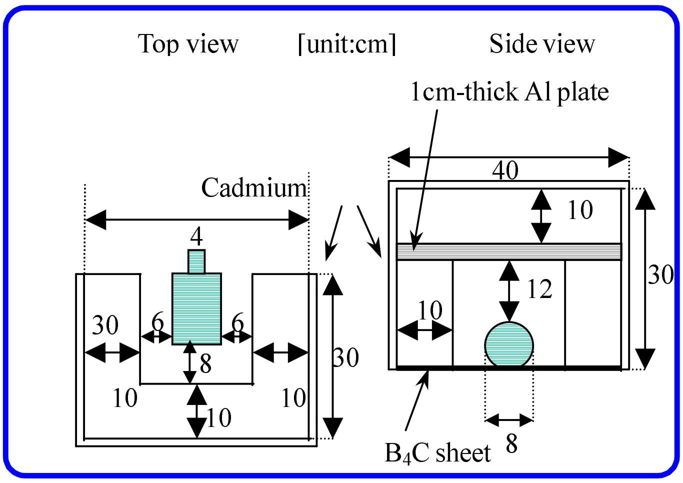


Fig.3 Ge detector arrangement for measurement of 'Groundshine'

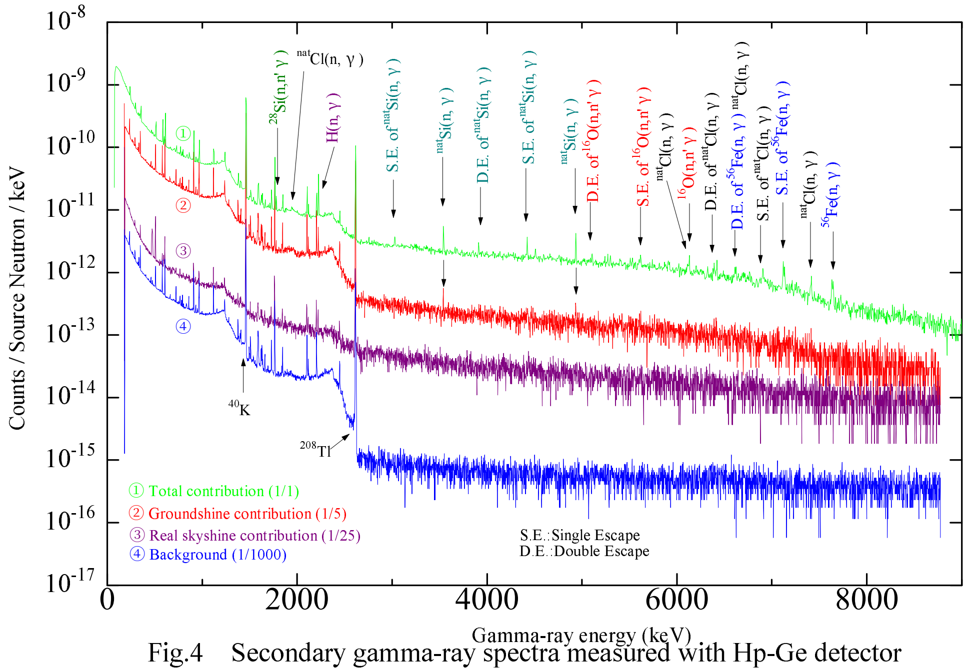


Fig.4 Secondary gamma-ray spectra measured with Hp-Ge detector at distance of 50m from the facility

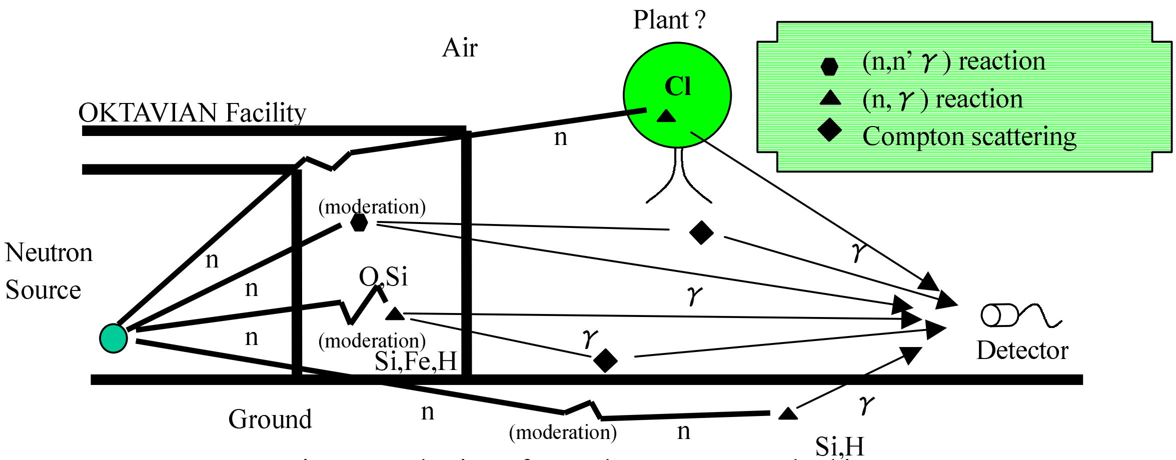


Fig.5 Mechanism of secondary gamma-ray skyshine

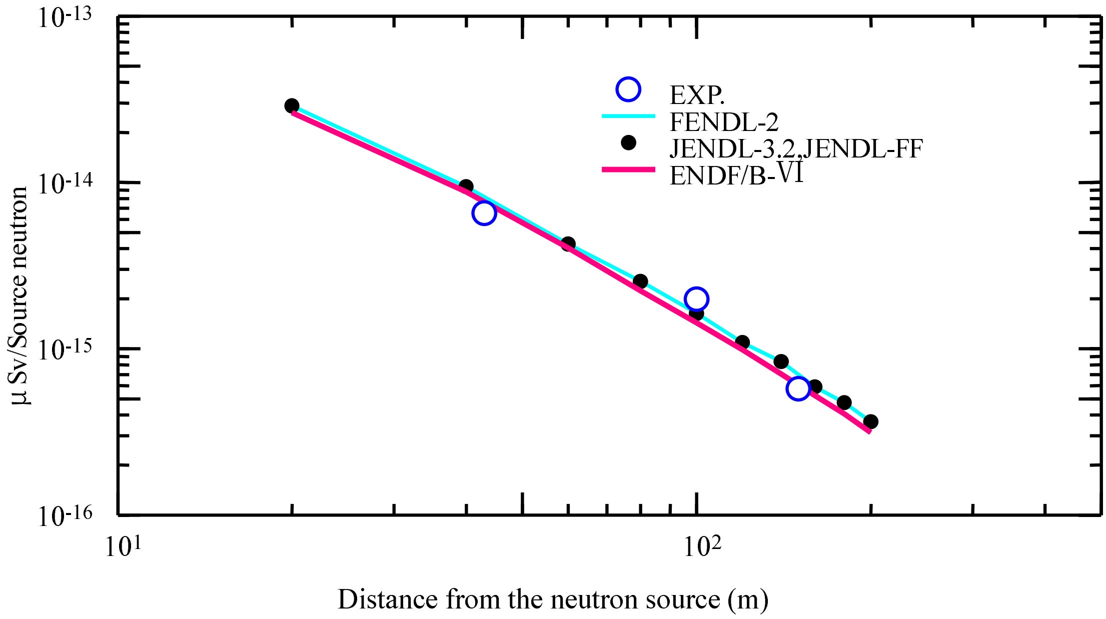


Fig.6 Comparison of measured dose equivalent with NaI detector and the calculations with MCNP-4B

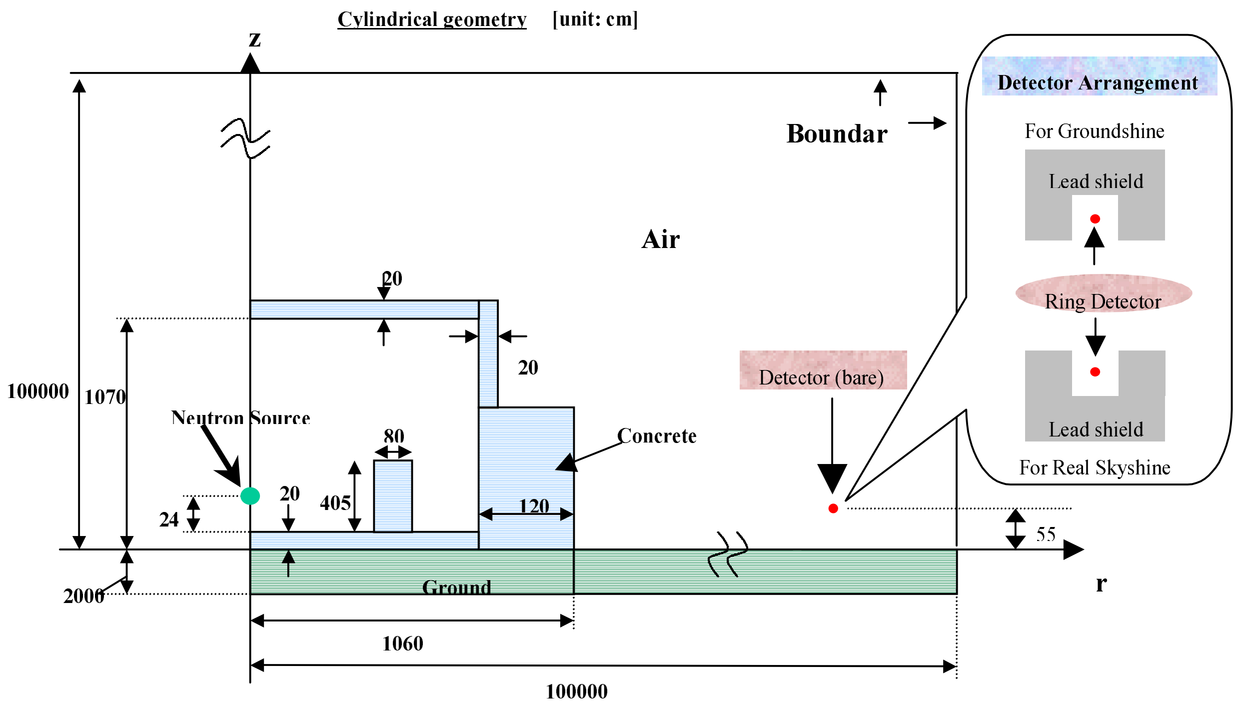


Fig.7 Two-dimensional model employed for MCNP calculation

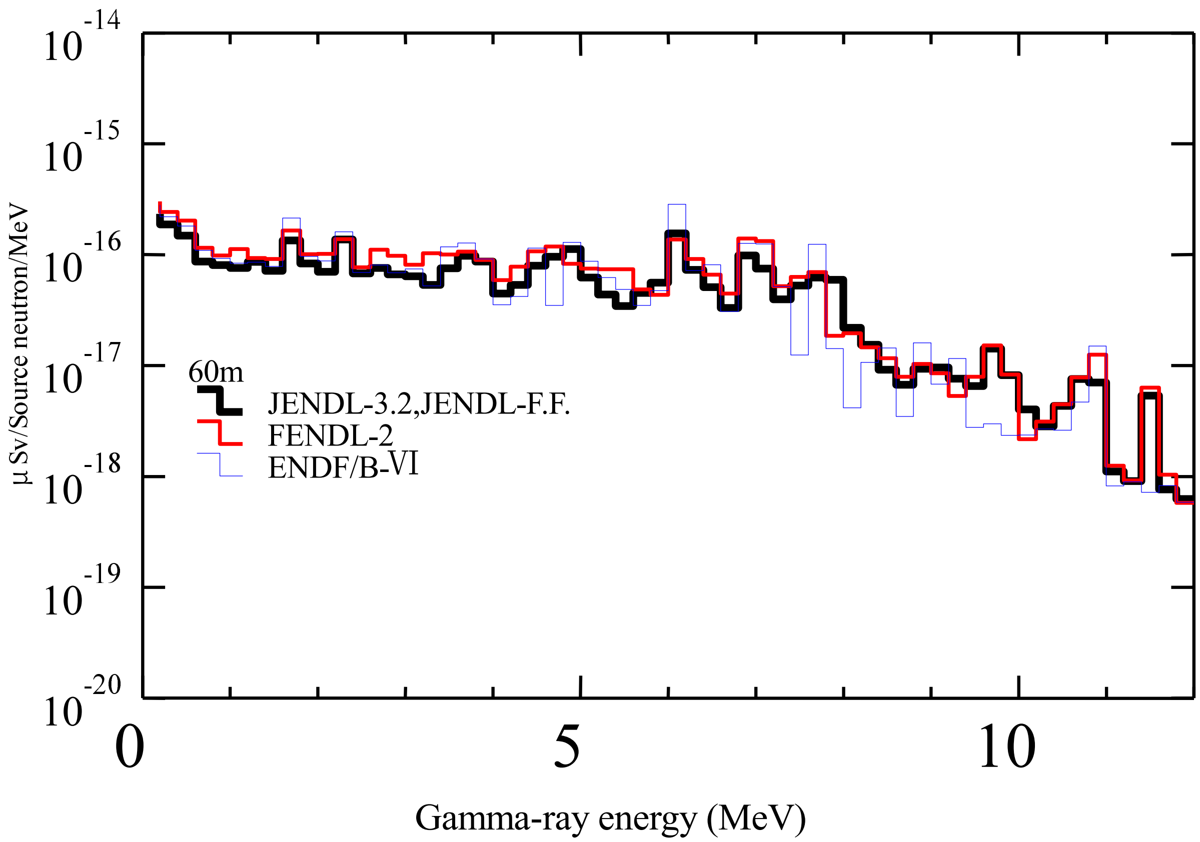


Fig.8 Calculated energy differential dose equivalent with MCNP-4B