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Monte carlo simulation by code of MCNP and experimental check for measuring thickness of materials for the specializing system of MYO-101

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Abstract. At present, thickness measurement of materials based on effect of backscattering gamma-ray has been widely used in industry in our country. The report presented research in measuring thickness of some materials such as paper, plastic, aluminum and steel with using the dedicated system of MYO-101, having scintillation detector of YAP(Ce) and gamma-ray of 60 keV of Am-241 source, by Monte-Carlo simulation using the code of MCNP. The simulation was checked by experimental measurements. The results were shown that they were in accordance with the range of error. This research has been useful for training activities with a view of human resources development in the field of application of nuclear technique in industry in Vietnam.

Keywords: Monte-Carlo simulation, Monte Carlo N-Particle, Backscattering gamma, Scintillation detector, Nuclear technique.

1. Introduction

At present, gamma backscattering method is applied in industry to measure the thickness of light materials, such as in the paper with the use of dedicated measuring systems using beta or low–energy gamma radioactive sources. The advantage of this method is to measure the thickness from only one side of the material. Radioactive source and detector are from the same side, and it is favorable in industrial conveyor systems; preferably with light materials, but the low efficiency [1]. Therefore, in order to support and compare them with experimental results, research method of Monte Carlo simulation by code of MCNP (Monte Carlo N-Particles) for thickness measurement based on the effect of backscattering gamma-ray is applied in this report [2,3].

Experimental equipment is the dedicated system of MYO-101 for measuring material thickness based on backscattering effect of gamma-ray, that was supported by NuTEC/JAEA, Japan in 2007. This system having sealed source of Am-241 (with activity of 370 MBq and gamma energy of 60 keV) was fixed in the dedicated scintillation detector of Yap(Ce) [Yttrium Aluminum Perovskite activated with Cerium] has been used for the experimental measurements in some of training courses on "Application of Nuclear Technique in Industry and Environment" in cooperation with NuTEC/JAEA, that have been held at the Nuclear Research Institute. The content of this report

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includes two parts: i) the theoretical simulation of measuring intensity for thickness of materials by the system of MYO-101 with using code of MCNP; ii) experimental measure on the thicknesses of light materials (such as paper, plastic, aluminum and thin stainless steel), and the results between the data of theoretical simulation and those of experimental measurements are compared together [3-5].

For backscattering effect, intensity of gamma-ray backscattered from the light material is given as a function of thickness of x as follows:

$$I(x) = I_0 + I_s[1 - \exp(-\mu\rho x)] \quad (1)$$

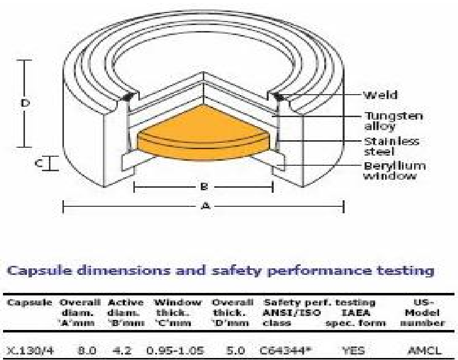
Where I_0 is an intensity of background radiation (without material);

I_s is a coefficient; $I_s(1 - \exp [(- (\mu/\rho) x])$ is an intensity of scattered radiation; μ is a mass attenuation coefficient; ρ is a density of material (g/cm^3); and x is a mass thickness of material (g/cm^2) [3].

2. Experimental

Simulation experiments using the cylinder source of Am-241 (with geometrial sizes and those simulated by MCNP are illustrated in Figure 1 and 2, respectively) to be placed in the scintillation detector of Yap(Ce) of the dedicated system of MYO-101 are carried out for measuring thickness of light materials (such as white paper, yellow paper, plastic, aluminum and thin stainless steel) based on the effect of backscattering gamma-ray.

Sheets of standard material with different thicknesses (size of 10x10 cm^2/sheet) are placed diametrically opposite with the center of Am-241 source (close to front face of source). Then measure count rate when placing additional standard sheets of the same material. Thickness of the material is gradually increased until obtained count rate reaches a saturation value [3].



Capsule	Overall diam. 'A'mm	Active diam. 'B'mm	Window thick. 'C'mm	Overall thick. 'D'mm	Safety perf. testing ANSI/ISO class	IAEA spec. form	US-Model number
X.130/4	8.0	4.2	0.95-1.05	5.0	C64344*	YES	AMCL

Fig. 1. Cross-section view of Am-241 source.

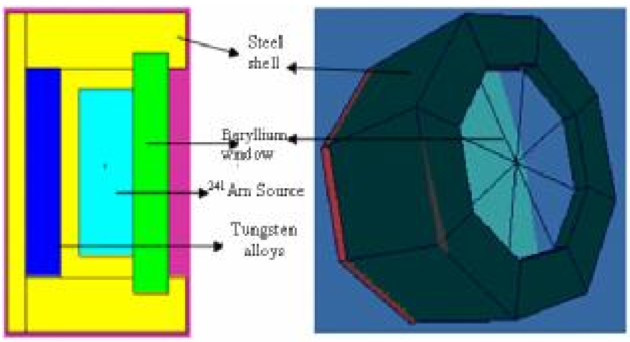


Fig. 2. 3D display map for Am-241 source simulated by MCNP (XZ).

The system of MYO-101 consists of blocks as follows: a detector with well scintillation crystal of Yap(Ce) having outer diameter of 60 mm, inner diameter of 15 mm, thickness of 1 mm, and aluminum incident window with thickness of 0.3 mm, and a photomultiplier working at high voltage of 1300 V; Am-241 source with activity of 370 MBq (10 mCi) in a disk shape (having overall diameter of 8 mm, overall thickness of 5 mm, active diameter of 4.2 mm, beryllium window with thickness of 1 mm) is placed in well of the crystal. The drawing of the detector is shown in Figure 3 and its simulation using MCNP (having adding block of Pb shielded near, front of the crystal) is shown in Figure 4 [2].

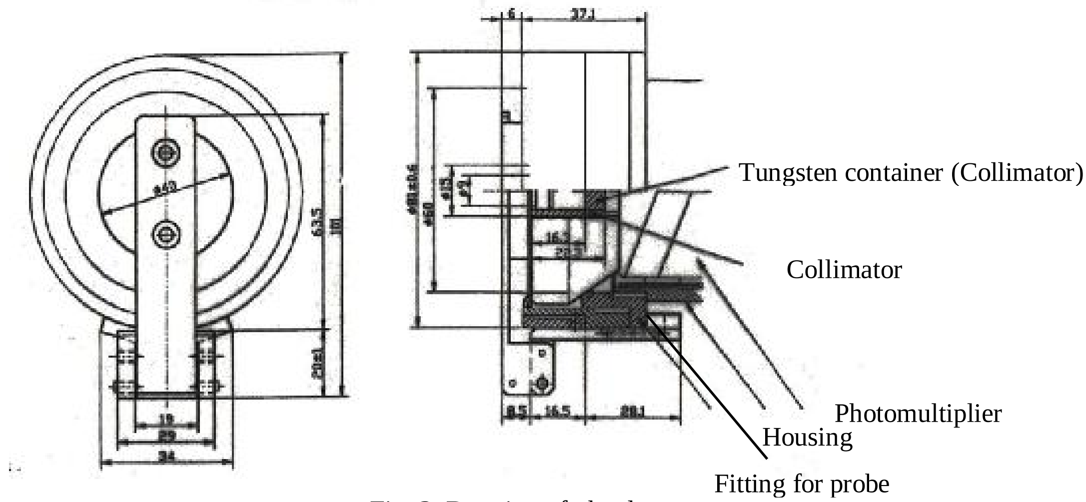


Fig. 3. Drawing of the detector.

Results of experimentally measured intensity I(cps) of scattering gamma-ray for different material are listed in Table 1. With model to be system of MYO-101, the program is runned with 50 million particles in order to obtain calculation data from MCNP. The calculation results from MCNP and experimentally measured ones are compared together [4]. From the data, graphs and fitted equations for different material could be built.

Table 1. Intensity of scattering gamma-ray for different material

White paper		Yellow paper		Plastic		Aluminum		Thin stainles steel	
Thickness (cm))	Intensity (cps)	Thickness (cm))	Intensity (cps)	Thickness (cm))	Intensity (cps)	Thickness (cm))	Intensity (cps)	Thickness (cm))	Intensity (cps)
0,00000	4148	0,00000	4148	0,00000	4148	0,00000	4148	0,00000	4148
0,01892	9562	0,01783	11585	0,14400	36146	0,13500	28305	0,07525	11462
0,04730	14236	0,03566	12715	0,28800	74350	0,27000	58491	0,15049	13958
0,09460	17546	0,08916	23447	0,43200	108025	0,40500	87406	0,22574	15351
0,18920	26949	0,17832	58111	0,57600	145655	0,54000	130753	0,30098	18519
0,28380	44433	0,26748	87313	0,72000	182938	0,67500	159905	0,37623	20983
0,37840	64088	0,35664	123031	0,86400	210076	1,35000	265989	0,75246	23507
0,61490	136523	0,44580	143624	1,00800	235077	1,48500	296762	0,82770	25272
0,89870	241336	0,53496	156071	1,15200	259568	1,62000	318022	0,90295	26387
1,04060	288142	0,62412	186952	1,29600	284713	1,75500	345582	0,97819	27530
1,13520	324791	0,71328	235219	1,44000	301782	1,89000	363337	1,05344	27561
1,41900	389961	0,80244	267896	1,58400	318880	2,02500	377415	1,12869	27288
1,51360	408444	0,89160	303467	1,72800	330860	2,70000	442502	1,50491	27339
1,60820	419666	0,98076	338028	1,87200	339014	2,83500	451070	1,58016	27170
1,70280	439361	1,06992	371921	2,01600	350013	2,97000	461154	1,65541	27412
1,89200	463949	1,15908	400024	2,16000	356679	3,10500	472244	1,73065	27608
1,98660	475032	1,24824	429553			3,24000	485455	1,80590	27452
2,08120	486167	1,33740	459869			3,37500	494754	1,88114	27547
2,17580	491244	1,42656	472848			4,05000	518898	2,25737	27400

2,27040	503952	1,51572	509158	4,18500	522152
2,36500	516179	1,60488	533999	4,32000	525706
2,45960	523625	1,69404	553640	4,45500	528051
2,55420	531286	1,78320	574533	4,59000	530954
2,64880	537556	1,96152	605563	4,72500	533328
2,74340	545102	2,13984	635462	5,40000	537593
2,83800	552917	2,31816	660465	5,53500	540718
2,93260	557884	2,49648	684751	5,67000	541790
3,02720	564076	2,67480	698921	5,80500	544384
3,12180	567563	2,85312	716016	5,94000	545849
3,21640	572741	3,03144	722884	6,07500	548231
3,31100	575864	3,20976	754801	6,75000	551659
3,40560	580593	3,38808	762326	6,88500	552283
3,59480	590764	3,56640	775050	7,02000	552077
3,68940	593266	3,74472	789016	7,15500	553123
3,78400	596906	3,92304	802255	7,29000	552492
3,87860	598615	4,10136	806165	7,42500	555629
3,97320	603899	4,27968	814162		
4,16240	609744	4,45800	814683		
4,25700	611430	4,63632	815940		
4,35160	613616	4,81464	817148		
4,44620	616402	4,99296	822473		
4,54080	617854	5,17128	832300		
4,63540	618425	5,34960	834359		
4,73000	621276	5,52792	835196		
4,82460	624694	5,70624	838234		
4,91920	627512	5,88456	839046		
5,01380	627013				

Table 2. Comparing features of materials to be measured through the experiments using the system of MYO-101 and calculated by MCNP simulation

Material	Experimental		MCNP		Deviation (%)
	Fitted equation	Saturated thickness (cm)	Fitted equation	Saturated thickness (cm)	
White paper	$I = 4148 + 695491,4500(1 - e^{-0,5852x})$	6,90	$I = 3330 + 668266,6900(1 - e^{-0,4019x})$	7,97	13,44
Yellow paper	$I = 4148 + 905544,3500(1 - e^{-0,5060x})$	6,87	$I = 3330 + 668266,6900(1 - e^{-0,44478x})$	7,88	12,87
Plastic	$I = 4148 + 489372,9270(1 - e^{-0,62533x})$	5,61	$I = 3330 + 668266,6900(1 - e^{-0,57446x})$	6,10	8,14
Alumi-num	$I = 4148 + 572493,6760(1 - e^{-0,51549x})$	6,80	$I = 3330 + 668266,6900(1 - e^{-0,49389x})$	7,10	4,19
Thin stainles steel	$I = 4148 + 23348,31840(1 - e^{-3,28106x})$	1,07	$I = 3330 + 668266,6900(1 - e^{-3,17505x})$	1,10	3,23

Proccessing of the measured results and drawing of graphs are done by software of Origin. The fitted equations and saturation thicknesses of 97% for each material are listed in Table 2, where I is pulse count rate (cps) and x is mass thickness (g/cm^2).

Graphs that describe dependence between counting rate and mass thickness are shown in Figure 5, 6, 7, 8 and 9 for white paper, yellow paper, plastic, aluminum and steel, respectively.

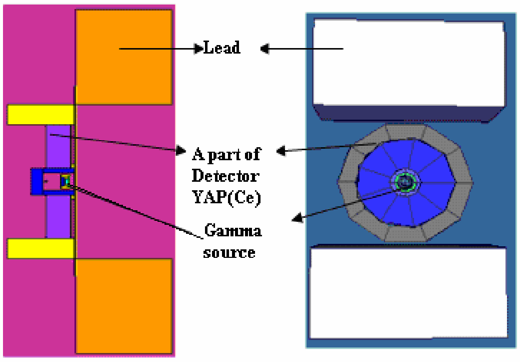


Fig. 4. Vertical drawing of the detector simuated by MCNP (XZ).

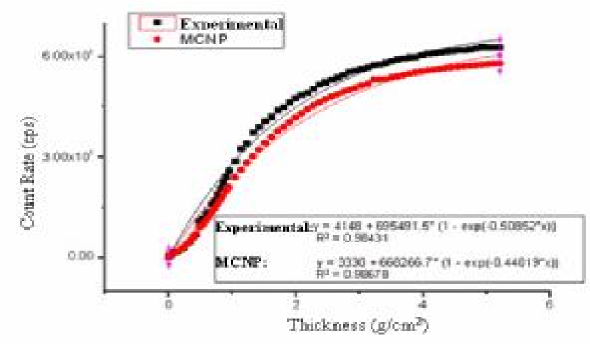


Fig. 5. Comparison of count rate versus thickness between simulation by MCNP and experimental measurement for white paper.

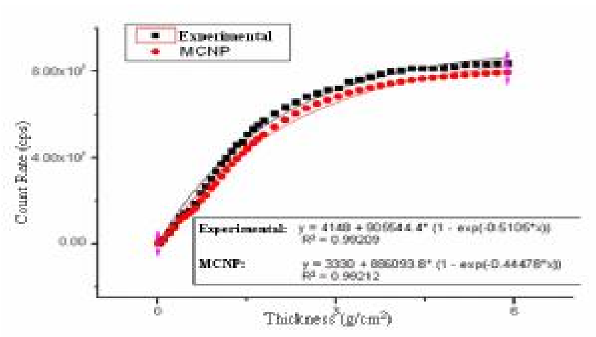


Fig. 6. Comparison of count rate versus thickness between simulation by MCNP and experimental measurement for yellow paper.

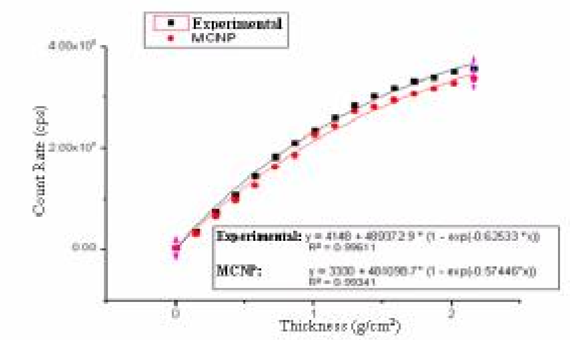


Fig. 7. Comparison of count rate versus thickness between simulation by MCNP and experimental measurement for plastic.

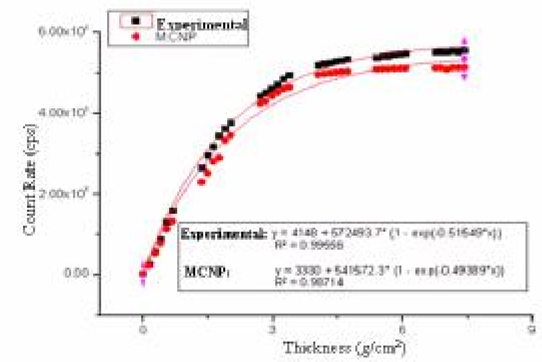


Fig. 8. Comparison of count rate versus thickness between simulation by MCNP and experimental measurement for aluminum.

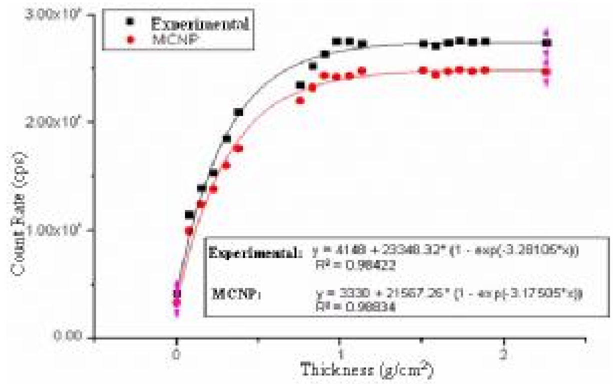


Fig. 9. Comparison of count rate versus thickness between simulation by MCNP and experimental measurement for thin stainless steel.

From comparison of the measuring experimentally data and the calculated ones by MCNP, it could be found out conversion coefficients (ratios) for mass absolution coefficient of µ from the experiments to MCNP for the system of MYO-101 are indicated in Table 3 [6].

Table 3. Conversion coefficients for mass absolution coefficient from the experimental data to simulation ones by MCNP for the system of MYO-101

No.	Material	Experimental (cm^2/g)	MCNP(cm^2/g)	Conversion coefficient
1	White paper	0,51	0,44	1,16
2	Yellow paper	0,51	0,44	1,16
3	Plastic	0,62	0,57	1,09
4	Aluminum	0,52	0,49	1,06
5	Thin stainless steel	3,28	3,18	1,03
	Average			1,10

From the comparison between simulation results and experimental ones, it is shown when increasing thicknesses of the same material, intensity of scattering gamma-ray will increase also. However, its intensity is increased up only to a certain level (namely saturated intensity), and is not increased further when increasing continuously the thicknesses. In the case of using source of Am-241, the light materials to be used commonly for measuring their thicknesses (based on the scattering effect) are sheets of white paper, yellow paper, plastic, aluminum and steel. When increasing thicknesses of the same material to the threshold value determined as in Table 1, the count rate will not be increased further, namely as the saturated thicknesse for each material (heavier material will give smaller saturated thickness) with energy and scattering angle according to the geometrical layout of the system of MYO-101. This is explained as follows: When increasing thickness of the material, gamma-rays will have an opportunity to cause more scattering, but in which competition between absorption process and scattering one in the material is increased. When increasing thickness of the materials to the critical value, the processes of scattering and absorption will be compensated. Thus, an amount of gamma-rays scattered from the material in order to crystal of the detector are not changed and it will create a saturated region [1,5,7].

From Table 2, it is shown that relative diviation between simulation results and measured experimentally ones are in the range of 3.3 - 15.5%. The diviation are gradually increased from steel (3.3%) to white paper (15.5%). This is understandable, in the case of very light materials such as the light paper, we have to use many sheets of the papers in order to increase their thickness, but missing thin layers of air between two adjacent panels in using MCNP. Therefore, there will be more diviation for very light materials such as paper in comparison with heavier materials such as stainless steel or aluminum.

3. Conclusion

Through comparison of the results calculated by MCNP and measured experimentally, it could be seen the advantage of MCNP program for simulating backscattering effect of gamma-ray in the case of the dedicated system of MYO-101 with using scintillation detector of Yap(Ce). From the initial results performed for several materials such as white paper, yellow paper, plastic, aluminum and thin stainless steel, conversion coefficients from MCNP to experiments were determined. These results will help for study in other materials by the simulation to predict linear absorption coefficient and saturated thickness before conducting experiments. In addition, the results of this research have also been very useful in training staffs and students in the field of application of nuclear technique in industry.

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