STUDY ON THE EFFICIENCY OF P-TYPE HPGe DETECTOR USING PHITS MC FOR SAMPLES WITH VOLUMETRIC GEOMETRY

Dr. Esra UYAR
Prof. Dr. Mustafa Hicabi BÖLÜKDEMİR

Gazi University, Faculty of Science, Department of Physics

RAD 2022 Spring Edition Conference
10th Jubilee International Conference on Radiation in Various Fields of Research
13-17 June 2022, Herceg Novi, Montenegro

SCOPE

- **Gamma Spectrometry – HPGe Detector**
- **Full Energy Peak Efficiency (FEPE)**
- **Monte Carlo (MC) Simulation Methods**
  - **PHITS MC Simulation Program**
- **Rounded and Sharp Modeling of Crystal Front Edge**

Gamma Spectrometry – HPGe Detector

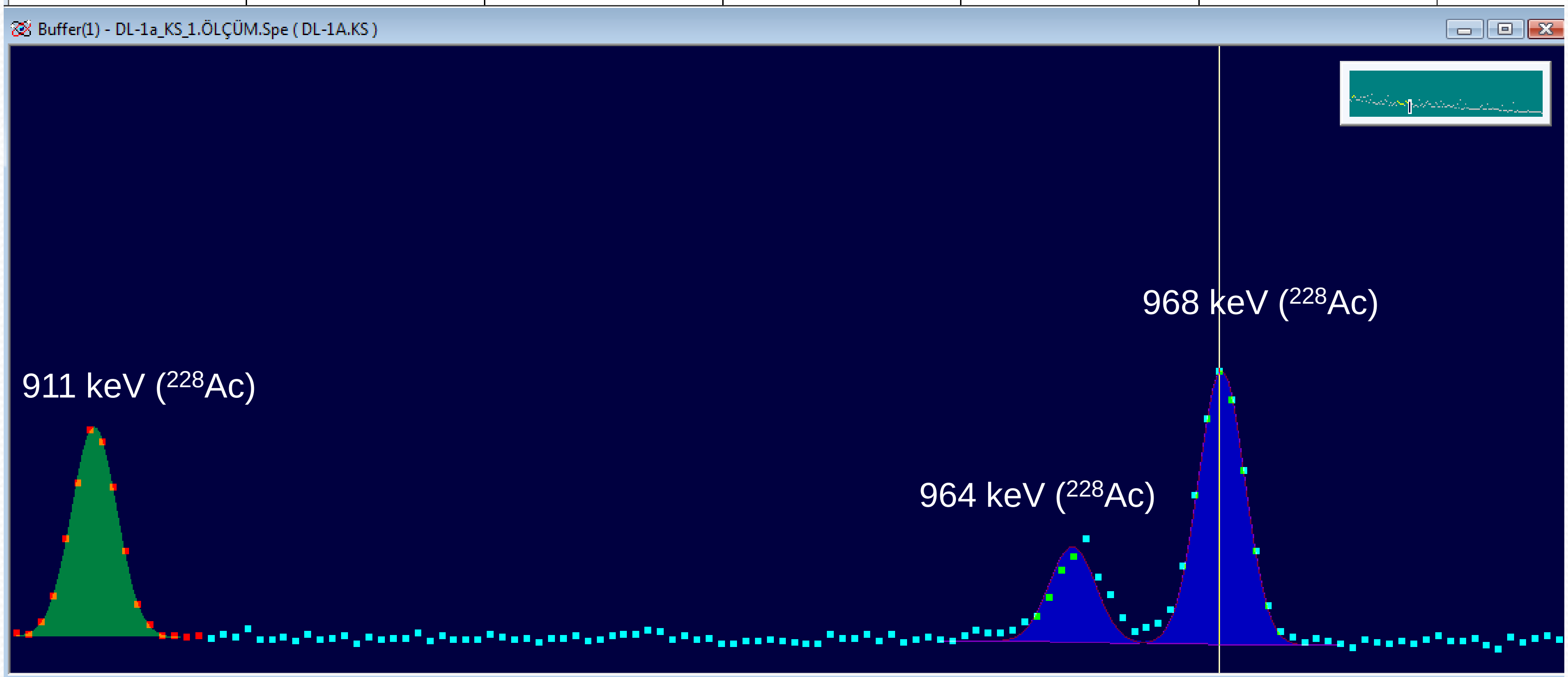
Gamma spectrometry is a system that allows the pulses, which are proportional to the energy of the gamma rays reaching the detector crystal, to be processed in a preamplifier and amplifier, and then digitized in the analog digital converter (ADC) and recorded as a spectrum in the memory of the multi-channel analyzer (MCA).

Gamma Spectrometry – HPGe Detector

- HPGe detectors are widely used in gamma spectrometry for identification and quantification of samples due to their high energy resolution

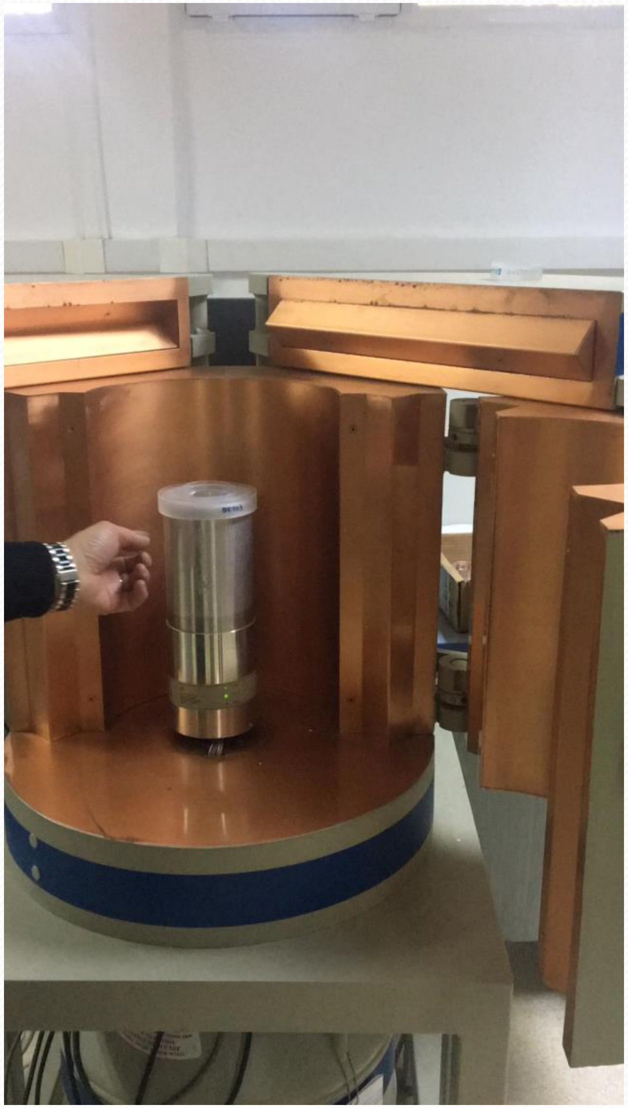
Analysis Results Table

Energy	FWHM (keV)	Area	Background	Nuclide	Bq
933.49	1.73	4442	3612	<Unknown>	
963.79	1.68	2054	2411	<Unknown>	
968.41	1.69	5890	2207	<Unknown>	
1000.41	1.63	1631	2898	<Unknown>	



HPGe Detector – Manufacturer value

Basic Detector dimensions		
Detector type	p-type	
Detector diameter	94.8	
Detector length	87.2	
Detector end radius	Hole diameter/2, nominal	
Hole diameter	11.2	
Hole depth	73.4	
Hole bottom radius	8 mm, nominal	
Miscellaneous Detector dimensions and materials		
Description	**Dimension**	**Material**
Mount cap length	130	Aluminum
End cap to crystal cap	5	N.A.
Mount cap base	3.2	Aluminum
End cap window	1.5	Aluminum
Insulator/shield	0.03	Mylar/Aluminized mylar
Outside contact layer	0.7	Lithium
Hole contact layer	0.003	Boron
Mount cap wall	0.76	Aluminum
End cap wall	1.3	Aluminum



FULL ENERGY PEAK EFFİCİENCY

The efficiency of the detector must be determined in order to obtain the activity value of the radionuclide of interest in the sample.

➡ It is the ratio of the photopic count at a given energy to the number of gamma rays emitted from the source.

- Source type
- The shape and active volume of the detector crystal
- Source-detector geometry
- interactions with the materials around the detector (detector window, other scatterers/absorbers).

FULL ENERGY PEAK EFFİCİENCY

Point source geometry

Volumetric source geometry
(6×5 cylinder)

Volumetric source geometry
(Tube)

Efficiency calibration for a particular detector-source geometry is not valid for other source-detector geometries. Therefore, efficiency calibration curves should be created for different source-detector geometries.

FULL ENERGY PEAK EFFİCİENCY

The full energy peak efficiency can be determined in two ways:

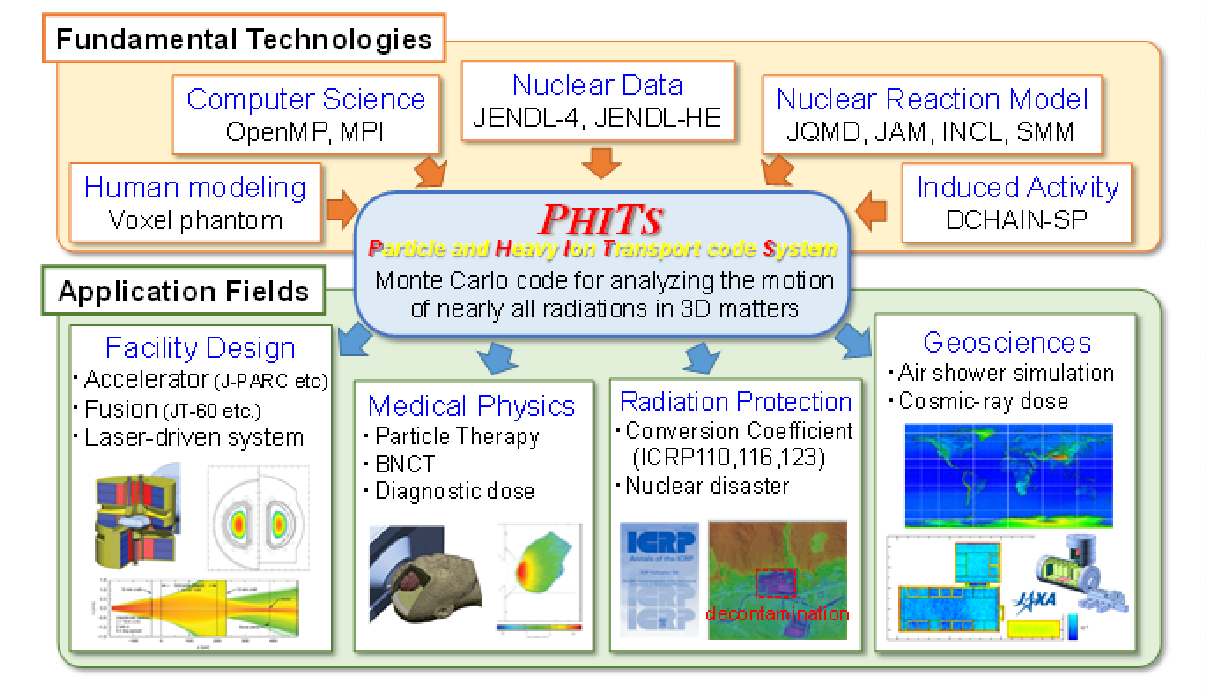
Experimental method **Monte Carlo simulation method**

- **The experimental method** is costly and time consuming, as well as the difficulties of accurately realizing measurement conditions such as measurement geometry, sample type and volume.

- Instead of the experimental method, which has many disadvantages such as being time consuming and costly, the use of the **Monte Carlo method** is increasingly common.

PHITS (Particle and Heavy Ion Transport code System)
MONTE CARLO SIMULATION PROGRAM

PHITS is developed by the Japanese Atomic Energy Authority in cooperation with many institutions in Japan and Europe, which has been popular in nuclear applications in recent years.



PHITS is an MC code that can transport most particle types with energies up to 1 TeV using several nuclear reaction models and data libraries.

MODELING OF HPGe DETECTORS WITH PHITS MC

In HPGe detector modeling with MC simulation;

- ✓ Detector diameter and length,
- ✓ Hole diameter and depth,
- ✓ End cap to crystal gap,
- ✓ End cap window material and dimension
- ✓ **Detector end radius (rounded or sharp edge geometry)**
- ✓ **Dead layer thickness**
- ✓ **Copper cooling rod thickness**

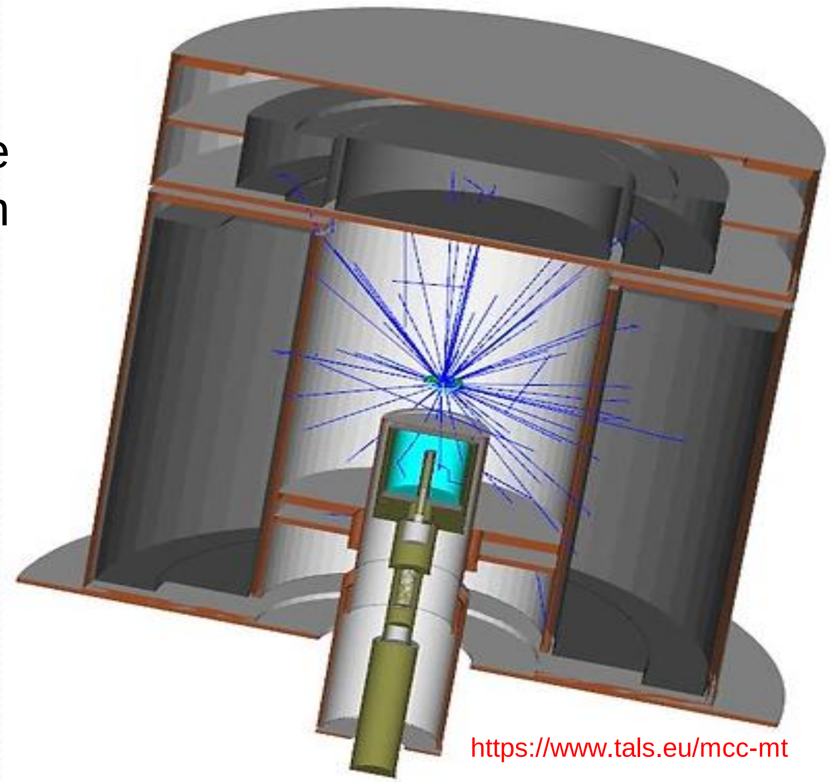
such as geometric parameters need to be determined accurately.

MODELING OF HPGe DETECTORS WITH PHITS MC

In the PHITS MC simulation code;
all geometric parameters of the detector such as dimensions of the crystal, end cap window thickness, the structure of the detector holder, dead layer thickness, etc. given by the manufacturer are defined and the HPGe detector is modeled.

The detector parameters provided by the manufacturer are of great importance in modeling the detector with the MC method

- The most important reason for the discrepancy between MC and experimental calculations is the lack of accurate information about the detectors geometric properties

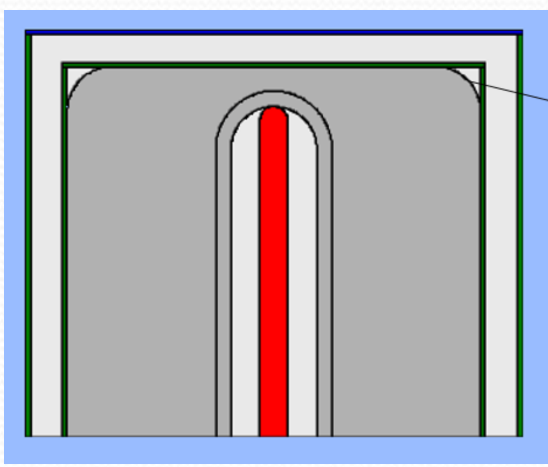


https://www.tals.eu/mcc-mt

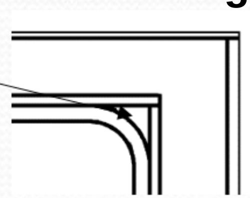
PHITS MC SIMULATION PROGRAM

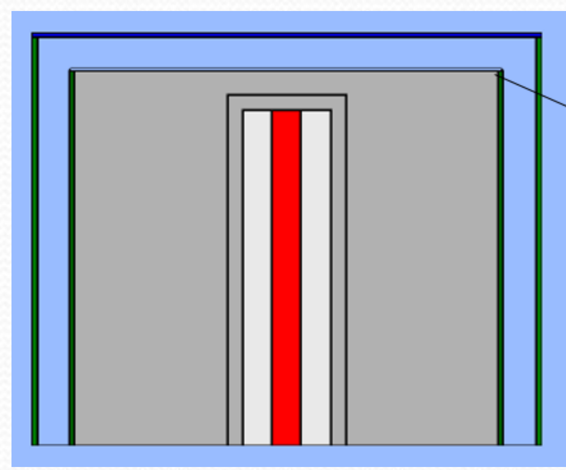
○ HPGe detector modeled in PHITS as rounded and sharp edge

- ✓ IAEA-RGU-1, IAEA-RGTh-1 and IAEA-RGK-1 reference materials were used.
- ✓ 9 energy values in the energy range of 46.5 keV - 1460.8 keV in these materials were modeled with PHITS as both rounded and sharp edge front faces and efficiency values were obtained.
- ✓ The number of particles in the study was 10^7 in all energy values, which was found to be sufficient for the required counting statistics less than 1% uncertainty.

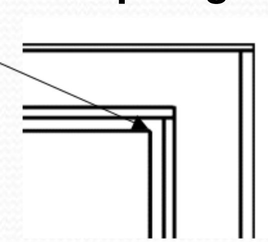


Rounded edge





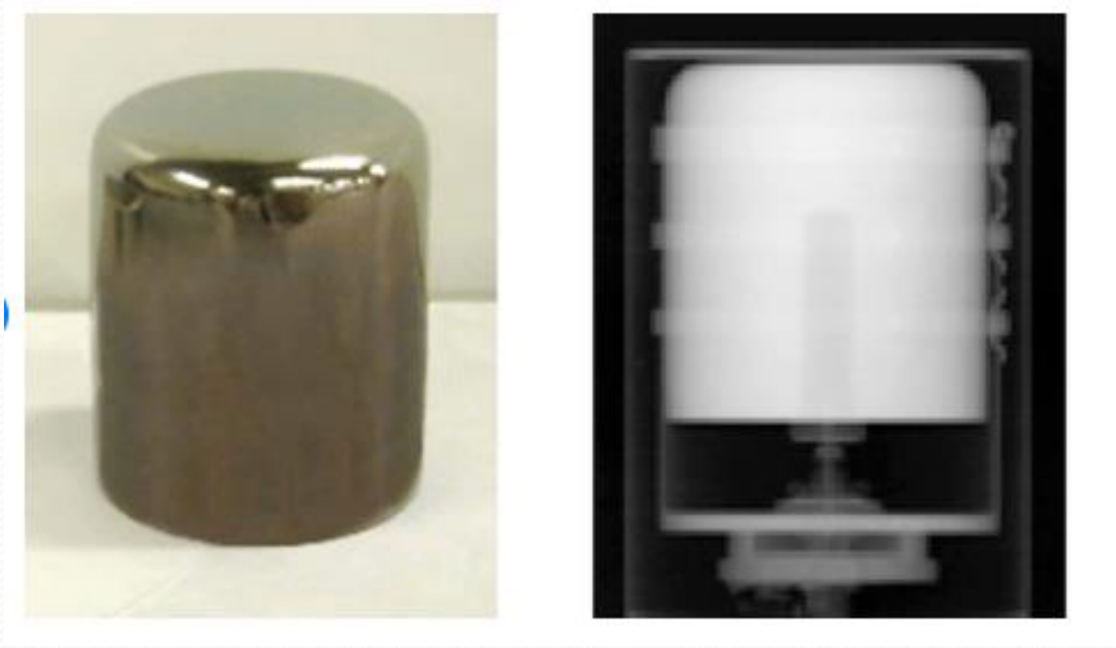
Sharp edge



ROUNDED AND SHARP EDGE MODELING

The sharp edge of the front face of the crystal reduces the detector performance and causes weak field regions. This problem is avoided by rounding the crystal front face in a process known as bulletization.

In this study, the effect of rounded or sharp modeling of the crystal face geometry, which is one of the geometric parameters of the detector, on the detector efficiency value was investigated.



RESULTS AND DISCUSSION

The sharp edge crystal has a larger active volume and a greater solid angle than a rounded edge crystal, if the crystal is not modeled as having a rounded edge, the detector efficiency will be overestimated.

Reference Material	Nuclide	Energy (keV)	Experimental efficiency (U_{exp} %)	PHITS MC calculated efficiency		Difference from experimental efficiency, %	
				Rounded edge	Sharp edge	Rounded edge	Sharp edge
IAEA-RGU-1	$^{210}Pb/^{238}U$	46.54	0.00375 (9.7)	0.00372	0.00385	0.8	2.7
	$^{234}Th/^{238}U$	63.29	0.02992 (3.3)	0.02997	0.03099	0.2	3.6
	^{235}U	143.76	0.10462 (3.6)	0.10619	0.10827	2.2	3.5
	$^{234m}Pa/^{238}U$	1001	0.04377 (3.3)	0.04408	0.04411	0.7	0.8
IAEA-RGTh-1	$^{228}Ac/^{232}Th$	129.07	0.09522 (3.7)	0.09678	0.09691	1.6	1.8
	$^{228}Ac/^{232}Th$	209.25	0.09500 (3.6)	0.09554	0.09617	0.6	1.2
	$^{228}Ac/^{232}Th$	911.21	0.04435 (3.7)	0.04457	0.04468	0.5	0.7
IAEA-RGK-1	^{40}K	1460.82	0.03419 (3.7)	0.03431	0.03436	0.4	0.5

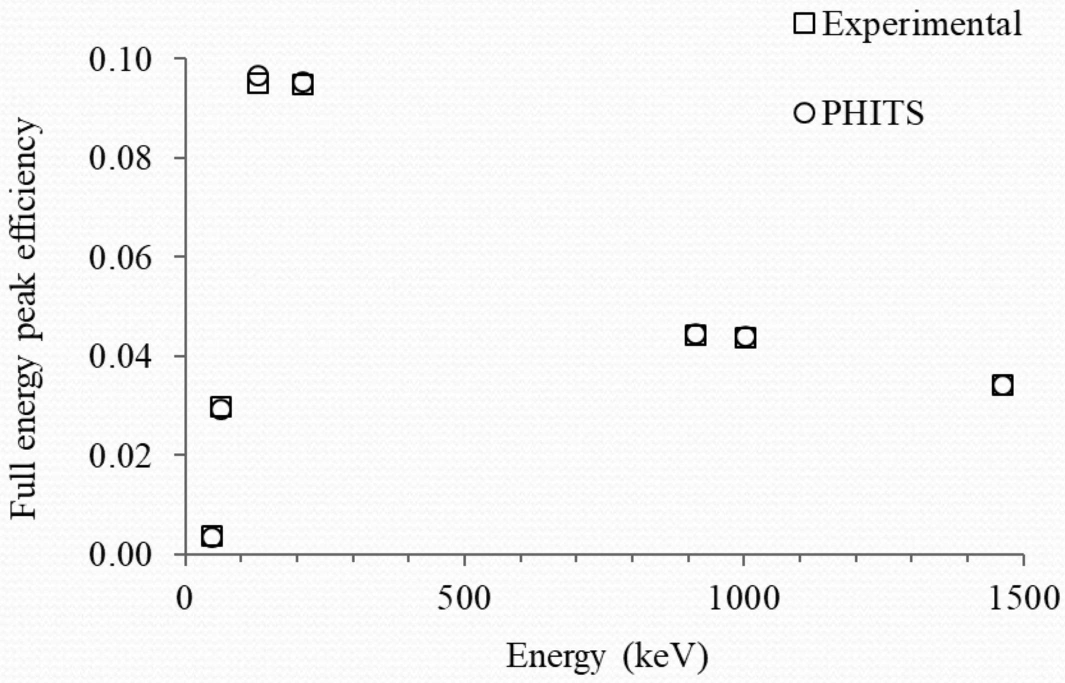
RESULTS AND DISCUSSION

In our previous study*, when the differences between the simulated efficiency values and the experimental values of the same detector at the detector-source distance of 12.5 cm in the point source geometry were examined, 11% difference was observed in the sharp edge geometry and 3.9% in the rounded edge.

*Bölükdemir, M.H., Uyar, E., Aksoy, G., Ünlü, H., Dikmen, H., Özgür, M., 2021. Investigation of shape effects and dead layer thicknesses of a coaxial HPGe crystal on detector efficiency by using PHITS Monte Carlo simulation. Radiation Physics and Chemistry 189, 109746.

RESULTS AND DISCUSSION

In this study, the differences between the simulated efficiency values obtained from the volumetric sources counted on the detector endcap and the experimental values were investigated. The difference was 3.6% maximum in the sharp edge geometry and 0.2% in the rounded edge at <100 keV.



RESULTS AND DISCUSSION

Thus, in the counts made directly on the detector endcap in volumetric geometry, it was seen that the difference in the geometry of the front edge of the crystal was not as much as the point source geometry counted at a certain distance from the detector.

This difference, which is caused by the solid angle between the source and the detector, shows that we should model the crystal as rounded in the volumetric source geometry. In this study, volumetric geometry, which is the most used geometry in routine gamma spectrometry, was modeled for the first time with PHITS MC. MC simulated results compatible with the experimental values were obtained. Therefore, this study has shown that PHITS MC can also be used successfully in volumetric source geometry.

ACKNOWLEDGMENTS

Experimental measurements of this study were carried out at Turkish Energy, Nuclear and Mining Research Authority (TENMAK), Nuclear Energy Research Institute, Gama Spectroscopy Laboratory within the scope of the cooperation protocol signed between TENMAK and Gazi University Faculty of Science. Our sincere thanks to Hasan Dikmen and Mine Özgür from TENMAK for their assistance with some experimental calculations

Thanks for your attention