High-Purity Germanium Measurement System

Model：TK-101

Fig. 1 TK-101 high purity germanium measurement system

Ⅰ. Product Introduction

TK-101 high purity germanium measurement system is the first domestic set of high-performance gamma-ray spectrometric system, providing an integral solution which consists of the high purity germanium detector, the refrigeration device, the digital multi-channel spectrometer, the low background radiation lead chamber, the gamma spectrum access and analysis software, the sourceless efficiency calibration software and so on. TK-101 integrates a number of patented technologies of Beijing Tai Kun Industrial Equipment Co.,Ltd.., with advantages of high energy resolution, highly automated radioactivity analysis, high system stability, high analysis result reliability, efficiency calibration without standard sources, complete operation in Chinese and so on. It is suitable for use by radioactive spectrum analysis professionals and non-professionals.

Ⅱ.Technical Specifications

1.1 High purity germanium detector

Model：Gamma-1

P-type coaxial detector, P-type wide energy range coaxial detector, N-type coaxial detector and well-

type detector are optional; for typical detector indicators, please see Tables 1 and 2. Table 1 Indicators of p-type coaxial (wide energy range) high purity germanium detector configured with TK-101

Model	**Relative Efficiency (%)**	**Capability Resolution (KeV)**		**Peak-to-Compton ratio**	**Peak shape (FWHM/KeV)**	
		122keV	1.33MeV		F W . 0 1M	FW.02M.
TK－10175P	10	0.825	1.75	41:1	1.9	2.65
TK－15180P	15	0.825	1.80	46:1	1.9	2.65
TK－20180P	20	0.850	1.80	51:1	1.9	2.65
TK－25185P	25	0.875	1.85	55:1	1.9	2.65
TK－30185P	30	0.895	1.85	58:1	1.9	2.65
TK－35190P	35	0.895	1.90	60:1	1.9	2.65
TK－40190P	40	1.0	1.90	62:1	1.9	2.65
TK－50190P	50	1.0	1.90	64:1	1.9	2.65
TK－60200P	60	1.0	2.0	68:1	2.0	3.00
TK－70200P	70	1.0	2.0	73:1	2.0	3.00
TK－80210P	80	1.0	2.1	77:1	2.0	3.00
TK－100220P	100	1.0	2.2	81:1	2.0	3.00
TK－120220P	120	1.0	2.2	83:1	2.0	3.00
TK－140220P	140	1.0	2.2	86:1	2.0	3.00
TK－160220P	160	1.0	2.2	88:1	2.0	3.00

Table 2 Indicators of well-type high purity germanium detector configured with TK-101

Model	Relative Efficiency (%)	Capability Resolution (KeV)		Well diameter	Volume（CC）
		122KeV	1.33MeV		
TK－1520W	15	1.1	2.0	10	90
TK－1522W	15	1.3	2.2	16	100
TK－2020W	20	1.1	2.0	10	110
TK－2022W	20	1.3	2.2	16	120

TK－2522W	25	1.1	2.2	10	130
TK－2523W	25	1.3	2.3	16	140
TK－3022W	30	1.2	2.2	10	150
TK－3023W	30	1.4	2.3	16	160
TK－3522W	35	1.2	2.2	10	170
TK－3523W	35	1.4	2.3	16	180
TK－4022W	40	1.2	2.2	10	190
TK－4023W	40	1.4	2.3	16	200
TK－6023W	60	1.3	2.3	10	280

Table 3 Indicators of N-type high purity germanium detector configured with TK-101

Model	Relative Efficiency (%)	Capability Resolution (KeV)		Peak-to-Compton ratio	Peak shape (FWHM/KeV)
		122KeV	1.33MeV		F W．0 1M
TK-10180N	10	0.665	1.80	40：1	1.9
TK-15185N	15	0.675	1.85	44：1	1.9
TK-20190N	20	0.690	1.90	48：1	1.9
TK-25190N	25	0.690	1.90	50：1	1.9
TK-30190N	30	0.715	1.90	44：1	1.9
TK-35200N	35	0.775	2.00	55：1	2.0
TK-40200N	40	0.800	2.00	57：1	2.0
TK-45210N	45	0.850	2.10	58：1	2.0
TK-50220N	50	0.900	2.20	58：1	2.0
TK-55220N	55	1.000	2.20	60：1	2.0
TK-60220N	60	1.100	2.20	60：1	2.0

1.2 Digital multi-channel

Model：Gamma-2

Fig. 2 **Gamma-2** digital multi-channel

TK-101 is equipped with digital multi-channel 2 **Gamma-2** with up to 16384 channels, developed by Beijing Tai Kun Industrial Equipment Co.,Ltd..; the multi-channels use military-grade electronic components, with stable and reliable performance. The appearance of 2 **Gamma-2** multi-channel is shown in Figure 2, with Technical Specifications as follows:

- Maximum data passing rate: greater than 100kcps;
- Coarse adjustment gain: 1,2,4,8,16 or 32 optional;
- Fine adjustment gain: 0.45 ~ 1 adjustable;
- Largest channel address: 16384;
- shaping time constant: rise time is adjusted from 0.8μs to 23μs, with 0.2μs per step; flat-top time is ranged from 0.3μs to 2.4μs, with 0.1μs per step, selected by the computer (automatically adjusted under most automatic optimization function);
- Linearity: integral nonlinearity ≤ ± 0.025%; differential nonlinearity ≤ ± 1%;
- Temperature coefficient: gain <35ppm / ° C; zero point <3ppm / ° C;
- Overload recovery: 1000 times overload is recovered to within 2% rated output within 2.5 times non-overload pulse width at maximum gain;
- Pulse anti-accumulation: with field value set automatically, the resolution of pulse pairs is 500ns;
- Signal processing: with digital spectrum stabilization, automatic pole-zero, digital gating baseline recovery and other functions;
- Data memory: 16384-channel non-volatile memory, with 2^{31}-1 counts capacity per channel;
- Memory segmentation (system conversion gain): 16384, 8192, 4096, 2048, 1024 or 512 channels selected by the computer,
- Digital spectrum stabilization: gain and zero point are controlled and stabilized by the computer;
- Automatic digital pore-zero adjustment: controlled by the computer, with manual or

automatic setting;

- Count rate display: displayed on the computer screen in real time;
- Dead time correction: accuracy (changed with peak area) <3% (0 ~ 50000cps);
- Communication interface: USB2.0;
- single-channel or twin channel: to provide a single MCA and dual MCA options;
- Dimensions : 252mm × 150mm × 50mm;
- Weight: 1kg;
- Operating temperature: -10 ~ 50 ℃。

1.3、Liquid Nitrogen Re-condensing Refrigerator

Model：Gamma-3

Fig. 1 GAMMA-3 liquid nitrogen re-condensing refrigerator

Ⅰ. Product Introduction

GAMMA-3 liquid nitrogen re-condensing refrigerator is developed by Beijing Tai Kun Industrial Equipment Co.,Ltd. after three years of research and development (shown in Figure 1); the product uses micro-electric refrigerator as the main working part, with ultra-low temperature refrigeration able to transform gaseous nitrogen in the Dewar bottle back to the liquid state, and maintain a long-term

liquid nitrogen level. Thereby the labor for frequent addition of liquid nitrogen is avoided to save manpower costs. Also, compared with the electric refrigerator, as refrigeration unit of the liquid nitrogen re-condensing refrigerator does not touch with the liquid nitrogen, without the deterioration to the resolution of the detector, reaching the resolution level of the conventional liquid nitrogen refrigeration, and in case of power failure the low temperature environment is maintained by reliable liquid nitrogen, thereby better protecting the continuity of the system work.

Ⅱ. Technical Specifications

- The service life is not less than 200,000 hours;
- With LED display, to display the remaining liquid nitrogen volume in real time;
- With a safety relief valve, to prevent risks due to high pressure in case of power failure of equipment itself;
- Unnecessary to add liquid nitrogen for nearly 24 months under the continuous power supply conditions;
- When the 30L liquid nitrogen storage tank is filled with liquid nitrogen, the detector can maintain the low temperature state in case of power failure, with liquid nitrogen supplied for more than seven days;
- Electric pulse tube cooling (Stirling electric refrigerator optional);
- With a numerical display mode: refrigeration time and liquid nitrogen level can be maintained at the refrigeration state, and an alarm can be issued when the refrigeration time remains less than 48 hours;
- Motor is used to collect the evaporated nitrogen and to compress them back to the liquid state;
- The average power consumption is less than 200W.

III. Applications

- As the supporting part for high purity germanium detector, and also for other scientific instruments working in the liquid nitrogen temperature zone.

1.4、Energy spectrum analysis software

Model：Gamma-4

TK-101 is configured with a gamma-ray energy spectrum analysis software Gamma-4 that has developed its own distinctive features as well as integrating the advantages of main energy spectrum analysis software products internationally; that is, based on the automatic analysis as navigation, analysis results are exported through the selective precise interactive analysis. Gamma-4 is the only commercial energy spectrum analysis software that is capable of accurate analysis of multiplet.

Gamma-4 integrates hardware control, data access, data analysis, report generation and quality control in one, and can obtain 10 energy spectrum data simultaneously, having good compatibility with Windows7, Windows8 and Windows XP, with the following main function:

- Spectrometer control: achievable parameter settings include: gain fine adjustment, start digital spectrum stabilization, adjustment of high voltage, real time / live time display, and setting of the upper and lower discrimination;
- Energy calibration: to fit precise positioning peak through a unimodal fitting; the user determines the corresponding energy of peak according to the knowledge, and the software provides nuclide peak information real-time query function;
- Peak searching: The first-order derivative and the second-order derivative method is used to find the isolated peak. On the basis of the fitting of the peak shape, the Mariscotti method is used to search the peak secondarily to determine the position of multiplet;
- Efficiency calibration: the software provides two functions. One is to call the efficiency calibration curve measured through test, and the other is to calculate results throughGamma-5 sourceless efficiency calibration software seamlessly connecting with this software; as sourceless efficiency calibration is used, a variety of complex correction functions are no longer required in the spectral analysis, such as solid angle correction and attenuation correction;
- Peak fitting: through background deduction by the peak fitting to distinguish multiplet the net counting rate is obtained. Gamma-4 provides an excellent multiplet resolution function, to

accurately analyze 20 multiplet using quasi-Newton method and Monte Carlo method and other numerical calculation method. The non-linear background deduction method is used, to automatically adapt to the trend of changes in energy spectrum. The peak shape adopts a Gaussian function or a Gaussian function plus front and rear exponential function trailing to fit peak shape, having excellent fitting ability for distorted peak form;

- Radioactivity calculation: For the different γ peak of the same nuclide, activity is calculated through the weighted average by considering the branching ratio and efficiency calibration factor. The nuclide attenuation and dead time correction during the measurement are also taken into account in the calculation of the radioactivity;
- Minimum detectable limit calculation: built-in Currie MDA, KTA MDA, PISO MDA, Critical level and other analytical methods for selection;
- Uncertainty analysis: the uncertainty of energy spectrum measurement results can be obtained by comprehensive calculation of the uncertainty of detection efficiency and uncertainty of the counting rate;
- Nuclide library for analysis: there are more than 3000 radioactive isotope spectral lines from ENSF (Evaluated nuclear structure data file), with spectral line information queried in real time in the use process.
- Software assessment: 100 energy spectrums from 16 international laboratories are used to assess the software, with analysis result accuracy meeting the requirements;
- User Interface: complete Chinese interface or complete English interface;
- Analysis process: Perform automatic analysis at first. Then The user can select the nuclide and energy peak according to the results of the automatic analysis and then conduct high-precision interactive analysis and output the reports. In general, the full automatic analysis is able to meet the users' needs. With the interactive analysis function, the user is allowed to add comments to the sample, to delete false peak in the spectrum, and add peak that is not detected in the automatic processing, and change the shape of fitting peaks;

- Report output: Output reports in TXT, PDF, HTML and XML formats.

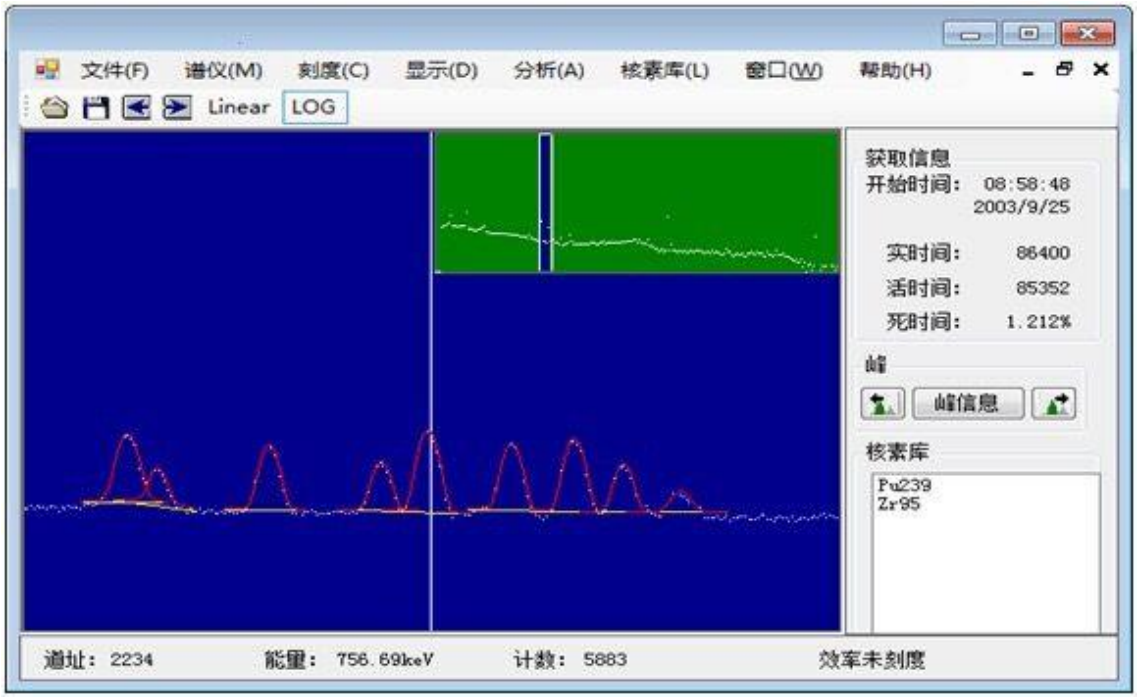

Fig. 3 Typical user interface for Gamma-4 energy spectrum analysis software

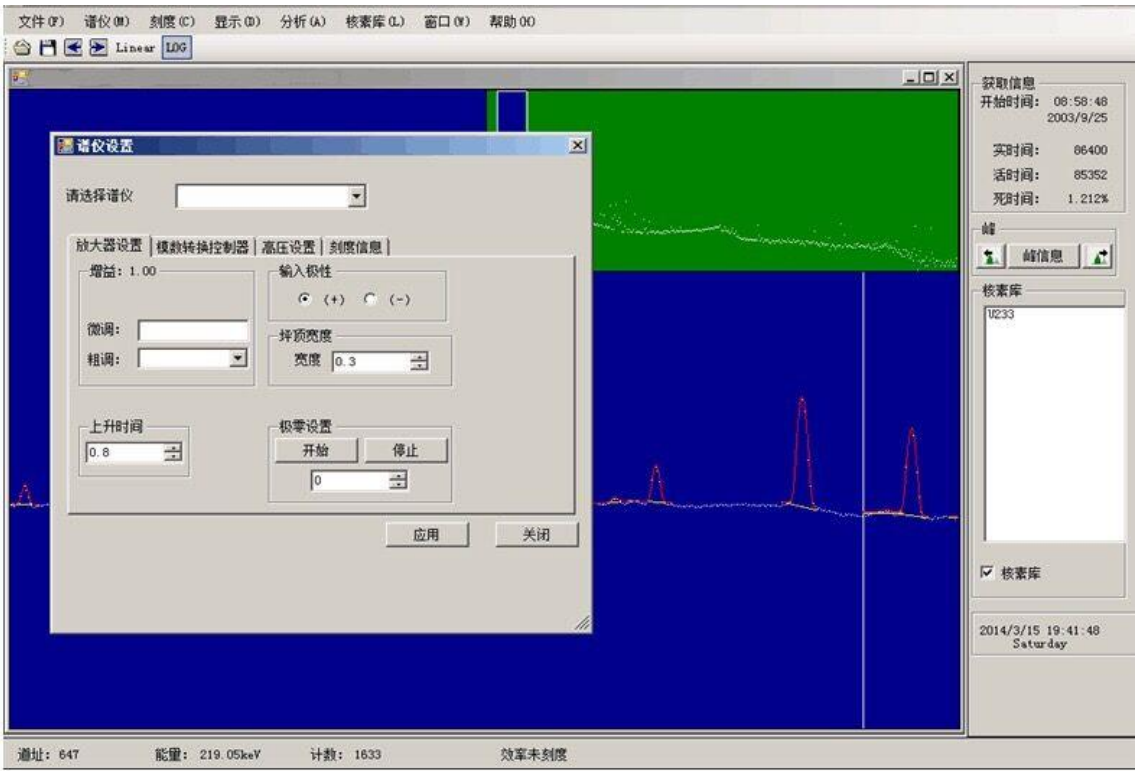

Fig. 4 Typical user interface for Gamma-4 software setting

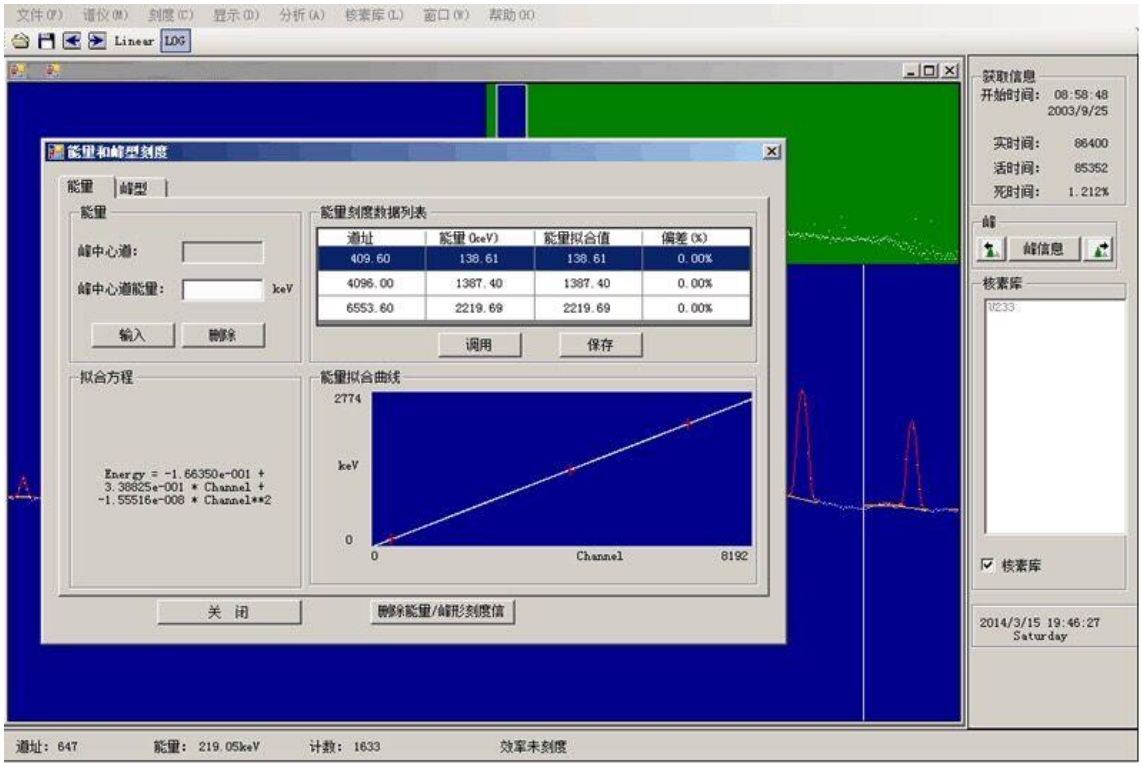

Fig. 5 Typical user interface for energy calibration

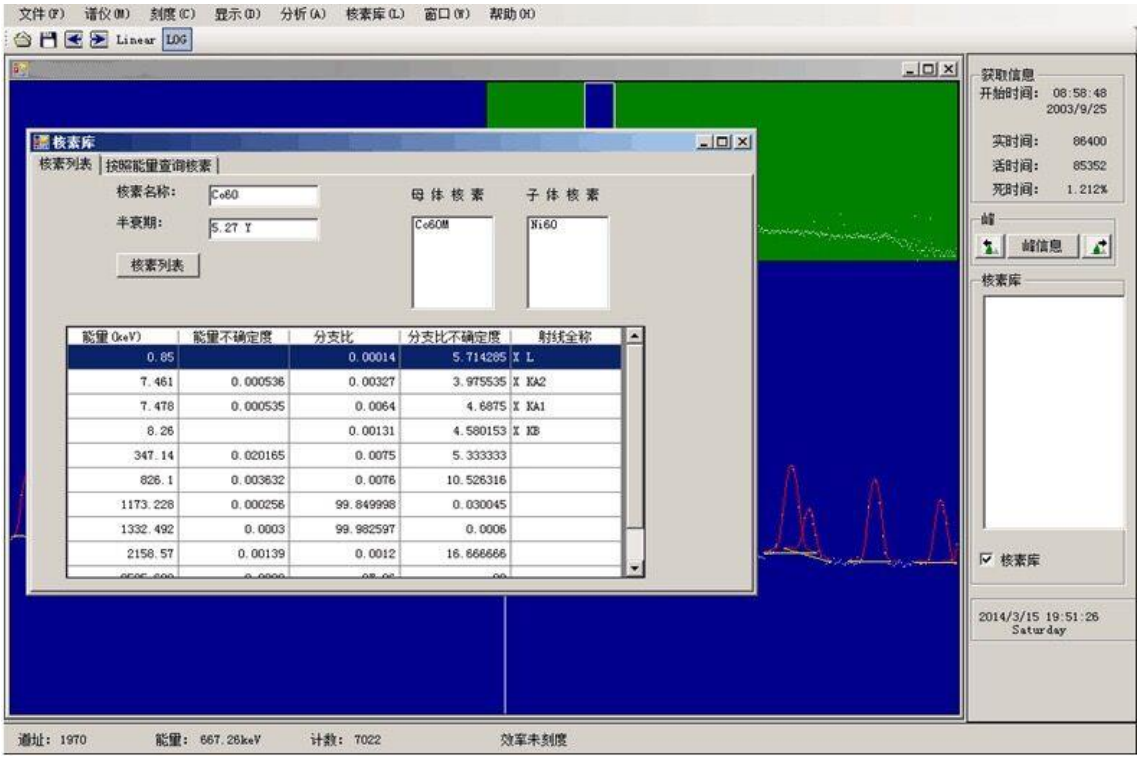

Fig. 6 Typical user interface for Nuclide library

Fig. 7 Typical user interface for interactive analysis

1.5. Sourceless efficiency calibration software

Model：Gamma-5

TK-101 is configured with sourceless efficiency calibration software Gamma-5, which is a patented product for the sourceless efficiency calibration of semiconductor gamma-ray detectors. The software has a powerful geometry and material modeling ability, with high calculation precision, fast speed, simple interface and easy operation. The correctness of the core algorithm is verified by more than 200 pieces of different shapes and energy body sources. The main functions are as follows:

- A powerful CAD software is used for modeling, to achieve rapid visual modeling for any shape of body source.
- The distance from the radiation source to the detector can be ranged from zero to infinity.
- Calibration energy ranges from 45keV to 7MeV.
- Integral control accuracy can be adjusted artificially, with the software default value of 3%. The relative error of the test results of the 200 sources is generally not greater than 10% between 45 keV and 80 keV, and 5% between 80 keV and 7 MeV.
- Efficiency calibration curve calculation time: for symmetrical body source (such as environmental sample source), the calculation costs less than 20 seconds. For asymmetrical body source, the calculation time is generally less than 10 minutes.
- Chinese and English interfaces.

Theory of sourceless calibration

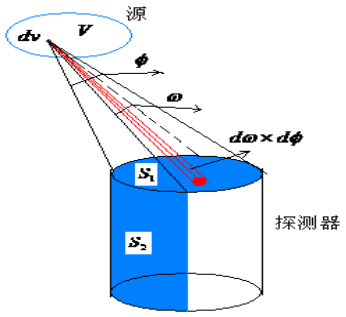

Fig8.γ detector sourceless calibration

V : volume source

dv： volume source element

S_1：area of detector end face to dv

S_2：area of detector side face to dv

$$\varepsilon_{eff,S_1}(E)=\int_{V,\omega\times\phi}\frac{1}{4\pi V}f_{att}(e,\omega,\phi)\times f_{eff}(e,\omega,\phi)\times\sin(\omega)d\omega\times d\phi\times dv \quad (1)$$

$$\varepsilon_{eff,S_2}(E)=\int_{V,\omega'\times\phi'}\frac{1}{4\pi V}f_{att}(E,\omega',\phi')f_{eff}(e,\omega',\phi,)\times\sin(\omega')d\omega'\times d\phi'\times dv \quad (2)$$

$$\varepsilon_{eff}(E)=\varepsilon_{eff,S_1}(E)+\varepsilon_{eff,S_2}(E) \quad (3)$$

（1）define geometric model of detector and volume source ,material model of volume source；

（2）calculate $f_{att}(E,\omega,\phi)$,

（3）calculate $f_{eff}(E,\omega,\phi)$；

（4）integral formula（1）and（2)。

Sourceless calibration for volume source:

（1）Building geometric model of detector and material model of samples；

（2）characterization；

（3）3D modeling of volume source；

（4） integral formula（1）and（2).

Advantage:

- No source;
- No contamination;
- High precision ,timesaving ,reliable；
- Strong geometric modeling ability, suitable for any geometry;
- It is not only suitable for calibration of conventional sample, but also suitable for calibration of unusual or difficult to deal with sample, such as cement, steel, gas, soil, air, filters, resin, etc. Suitable for calibration of any material, the density of arbitrary, arbitrary shape, the size of the sample;
- It is suitable for calibration of the samples of any base material and shielding material.
- It is suitable for any collimator and shield.

- Saving sample preparation time. The software can accurately model and calibrate according to the sample situation, so it does not take a lot of time to prepare samples.
- It can make sample measurement of large scale and avoid unrepresentative caused by sampling process.
- Rapid survey. Save the time and cost of sampling, packing, and transportation preparing sample and testing in laboratory.
- Avoid the risk of accidents caused by sampling, such as high temperature, high pressure, highly corrosive, highly radioactive objects sampling, climbing stairs, etc.
- Avoid sampling of difficult to sample, such as deep cement, steel, soil, radioactive waste in containers, pipes, ground, and etc.

Typical interface of Gamma-5

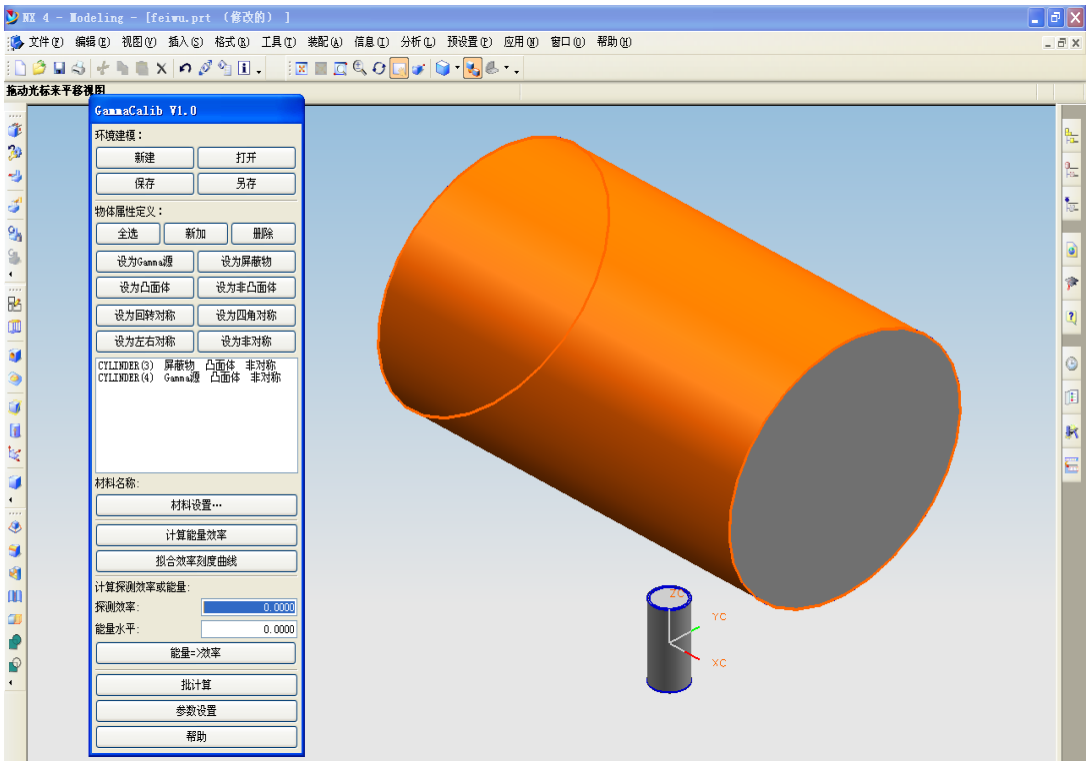

Fig. 9 Typical user interface for barreled radioactive waste measurement

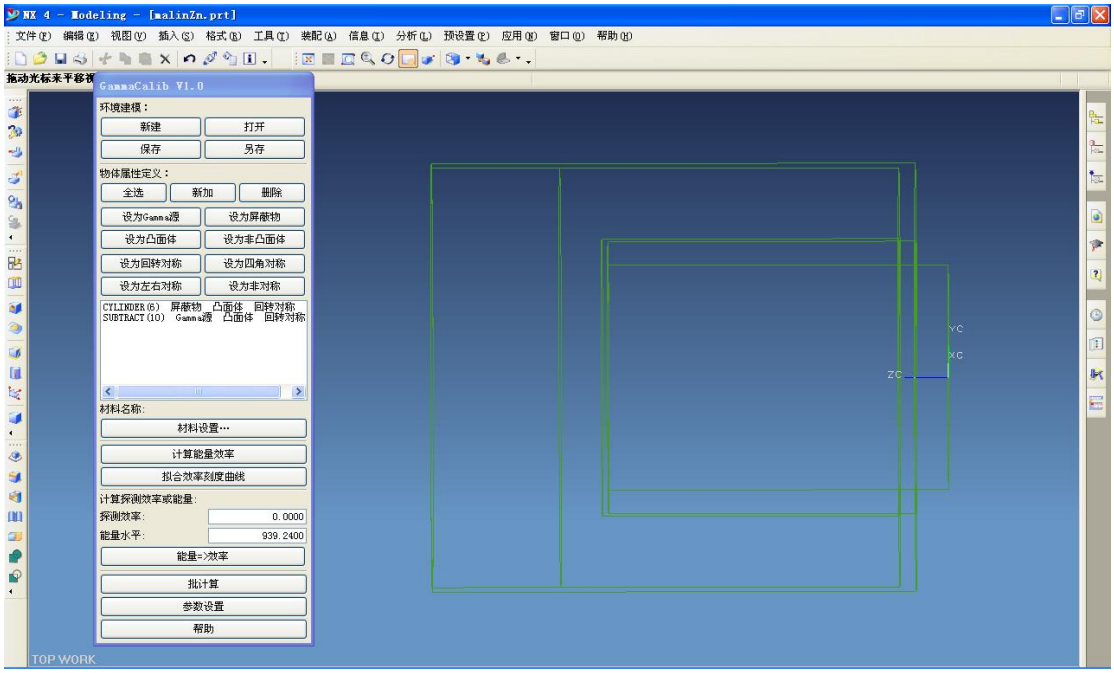

Fig. 10　Typical user interface for Marinelli Beaker measurement

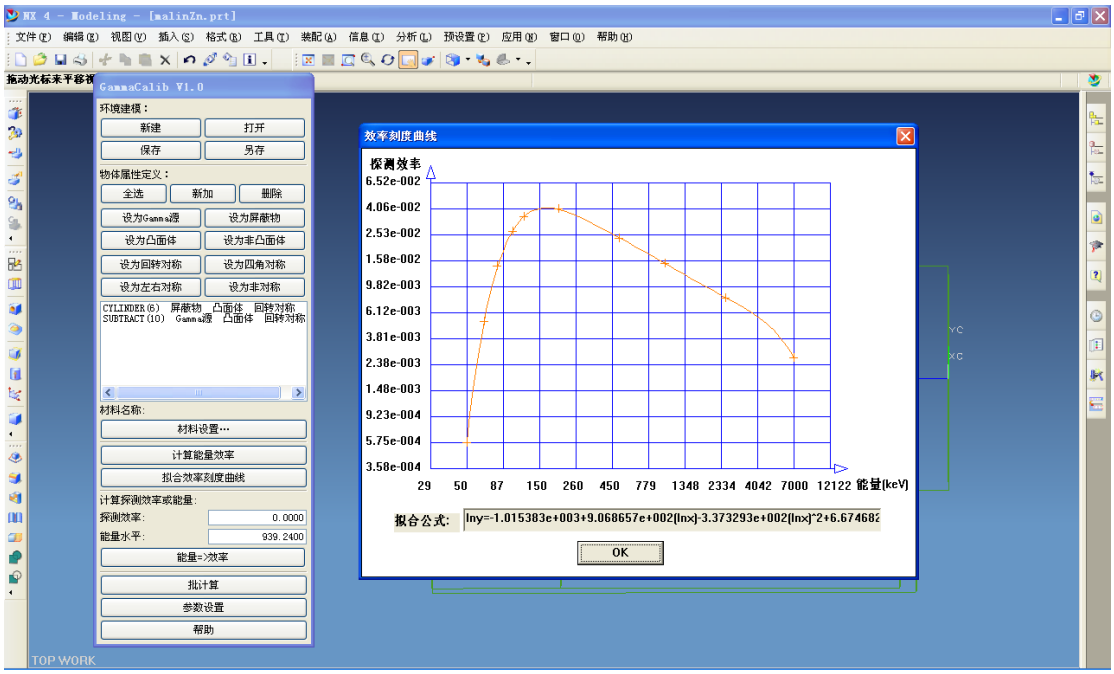

Fig. 11Typical user interface for efficiency calibration graph

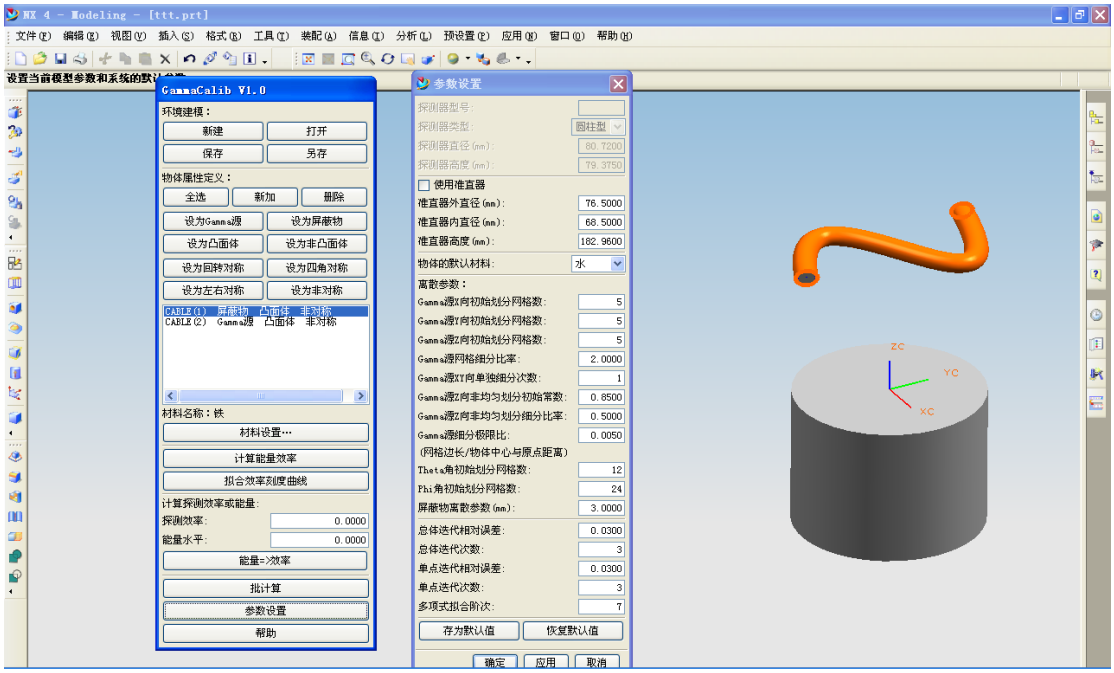

Fig12. Typical user interface for parameter setting

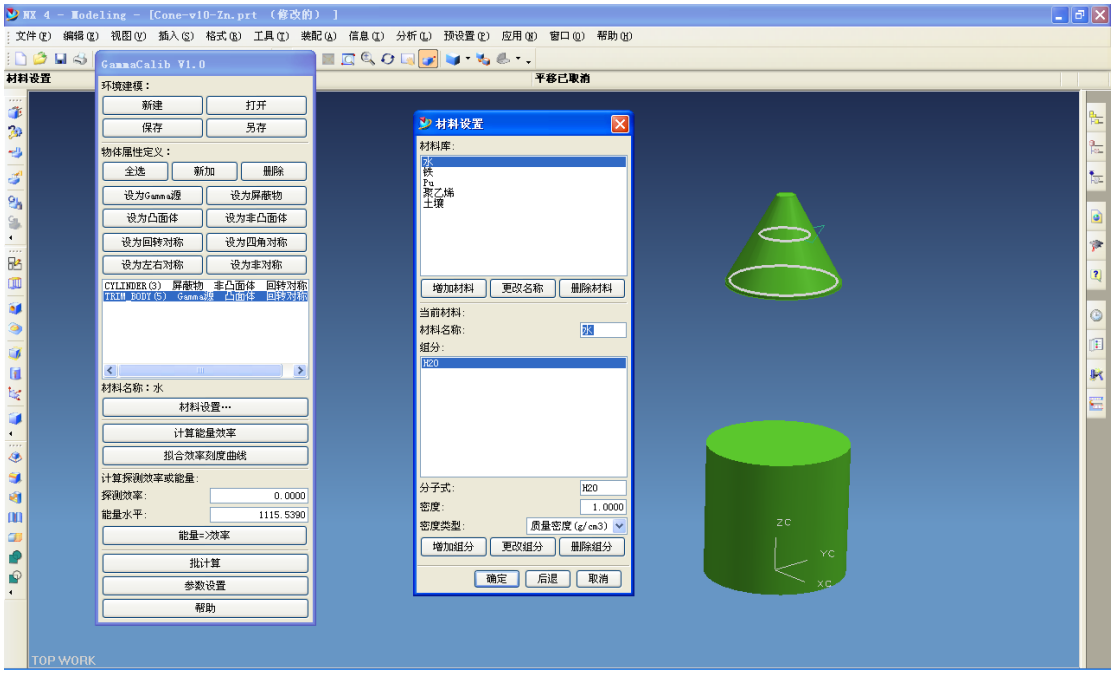

Fig13.Typical user interface for material definition

Precision of Gamma-5 software

- Six kinds of samples：Marinelli Beaker(1L)、cylinder（Φ50×50mm)、cube（40×40×40mm)、Sphere (Φ50mm)、Cone（Φ50mm，H:50mm）and filter paper。For volume source，different detecting position resulting 200 cases in nature.

Fig. 14　six kinds of volume source

- Positing the volume source to the detector from 3 directions.
- Axial：distance to detector 0cm,10cm,25cm,40cm
- Horizontal direction：distance to detector 0cm,10cm,25cm,40cm
- 45° direction：0cm，10×10cm，20×20cm

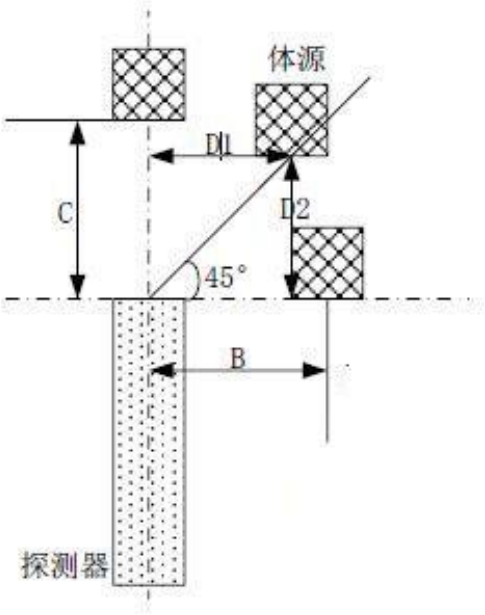

Fig. 15　relative position of volume source and detector

- Volume source with energy from 59.54ke to 3253.4keV，total 18 peaks，the specific activity of samples has been measured in Metrology station .
- Comparing calculation and measuring we find that energy under 80keV，the relative error is 10% , energy over 80keV,the relative error is 5%。

Detector characterization for use of Gamma-5 software

Each detector must be characterized in Metrology Institute before use of Gamma-5 software.

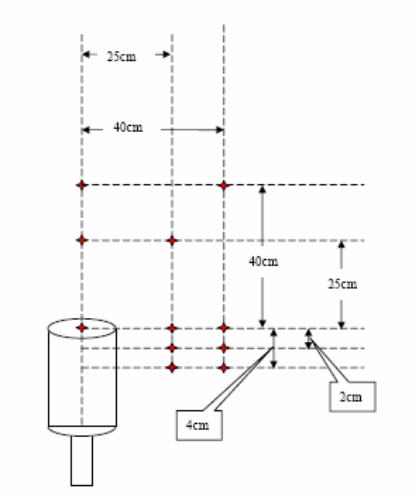

Fig16　position of detector characterization

Table4. Result of characterization

Position	**Result**	**^{241}Am 59.54keV**	**^{137}Cs 661.66keV**	**^{60}Co 1173keV**	**^{60}Co 1332keV**
(0.0 , 0.165)	Results of the experiment	0.3401	0.07555	0.04587	0.04109
	Uncertainty（%，K=1）	0.79	0.91	0.97	0.97
	Calculation	0.3563	0.7568	0.04696	0.04224
	Relative error(%)	0.28	0.75	2.4	2.8
(0.0 , 15.0)	Results of the experiment	0.008721	0.002441	0.001586	0.001442
	Uncertainty（%，K=1）	0.82	0.87	0.78	0.77
	Calculation	0.8692	0.002349	0.001552	0.004014
	Relative error(%)	0.3	3.7	2.2	2.8
(0.0 , 25.0)	Results of the experiment	0.003412	0.001010	0.000662	0.000604
	Uncertainty（%，K=1）	0.82	0.86	0.77	0.76
	Calculation	0.3403	0.0009581	0.0006358	0.000581
	Relative error(%)	0.3	5.1	4.0	3.8
(15.0, 15.0)	Results of the experiment	0.005658	0.001536	0.000988	0.000898
	Uncertainty（%，K=1）	0.82	0.86	0.77	0.76
	Calculation	0.005681	0.001524	0.000994	0.000902
	Relative error(%)	0.4	0.8	0.5	0.5
(25.0, 25.0)	Results of the experiment	0.002274	0.0006174	0.0003933	0.0003586
	Uncertainty（%，K=1）	0.82	0.87	0.77	0.77
	Calculation	0.002309	0.0006202	0.0004004	0.0003626
	Relative error(%)	1.5	0.5	1.8	1.1
(4.30, -1.50)	Results of the experiment	0.1419	0.04361	0.02766	0.02500
	Uncertainty（%，K=1）	0.79	0.89	0.89	0.89
	Calculation	0.1464	0.4196	0.02721	0.02433

	Relative error(%)	3.2	3.8	1.6	2.7
(15.0, -1.50)	Results of the experiment	0.01383	0.003975	0.002525	0.002286
	Uncertainty（%，K=1）	0.82	0.85	0.76	0.76
	Calculation	0.1461	0.004095	0.002623	0.002381
	Relative error(%)	5.7	3.0	3.9	4.2
(25.0, -1.50)	Results of the experiment	0.005007	0.001462	0.000938	0.000847
	Uncertainty（%，K=1）	0.83	0.87	0.78	0.78
	Calculation	0.005228	0.001505	0.000971	0.000873
	Relative error(%)	4.4	3.5	3.6	3.1
(4.30, -2.50)	Results of the experiment	0.1714	0.05197	0.03249	0.02932
	Uncertainty（%，K=1）	0.79	0.88	0.89	0.89
	Calculation	0.1761	0.050223	0.03208	0.02868
	Relative error(%)	2.7	3.4	0.85	2.2
(15.0, -2.50)	Results of the experiment	0.01432	0.004073	0.002593	0.002345
	Uncertainty（%，K=1）	0.82	0.85	0.76	0.76
	Calculation	0.01506	0.004200	0.002695	0.0024409
	Relative error(%)	5.2	3.1	3.9	4.1
(25.0, -2.50)	Results of the experiment	0.005057	0.001473	0.000946	0.000859
	Uncertainty（%，K=1）	0.83	0.87	0.77	0.77
	Calculation	0.005270	0.001524	0.000983	0.0008872
	Relative error(%)	4.4	3.4	3.9	3.3

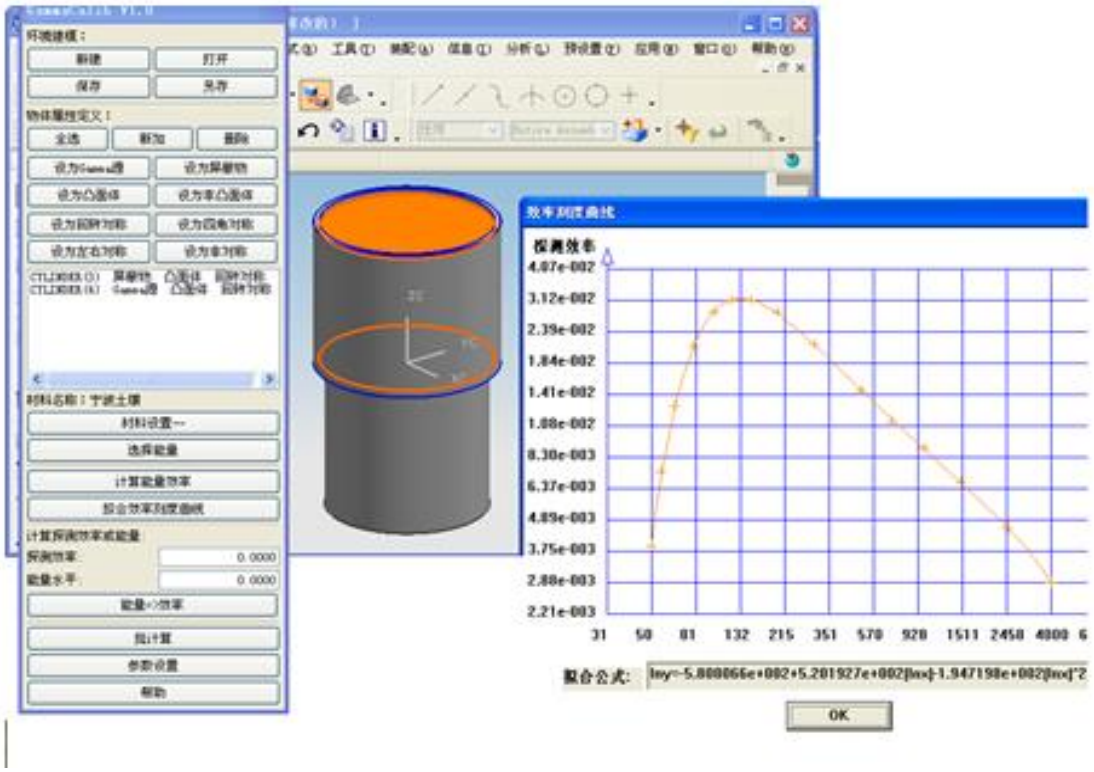

Fig. 17Typical interface of passive efficiency calibration softwareGamma-5

1.6. Lead chamber

Model：Gamma-6

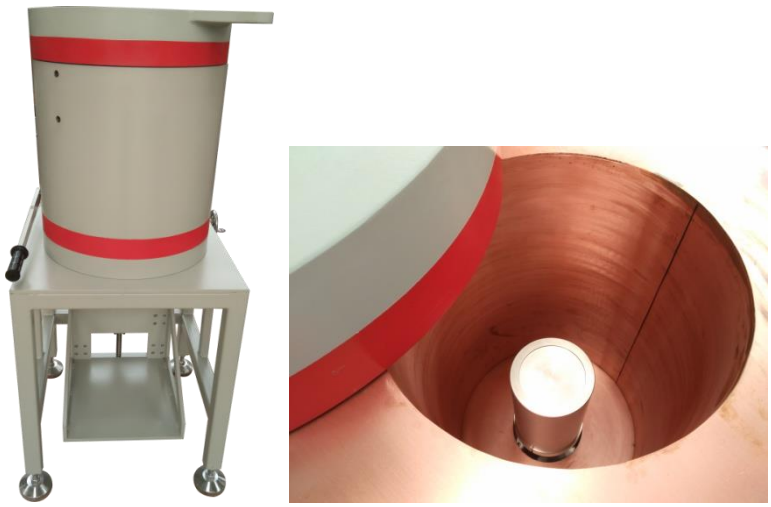

Fig. 5 Gamma-6 lead chamber

TK-101 is equipped with a background Lead chamber-Gamma-6 developed by Beijing Tai Kun Industrial Equipment Co.,Ltd.., as shown in figure 5 below.

- Outer material: 1cm low-carbon steel;
- Middle material: 10cm low background radiation lead 4π direction shielding;
- Inner material: 3 mm oxygen-free copper, to absorb X-ray;
- Press-type open door design with top translation;
- Material of the load-bearing table: low carbon steel;
- Floor area: 65cm x 65cm;
- Cavity size: Φ307mm x 404mm;
- Weight: 1.1 tons.

1.7. Refrigeration device

Model：Gamma-7

Liquid nitrogen refrigeration, electric refrigeration or condensate refrigeration device are optional.

Ⅰ.Main Features：

- Multi-channel, high-voltage modules and other electronic systems use military-grade devices, with a special temperature stability feature provided; the system has excellent long-term stability, and has been working continuously for a month, with the energy resolution maintained less than 1.9KeV at 1460.8KeV.

- Energy spectrum analysis is mainly automatic, with auxiliary interactive analysis, especially suitable for non-professionals.
- Ray information of more than 3000 isotopes is provided; nuclide library is tightly combined with energy spectrum analysis software for easy operation.
- A powerful multiplet analysis ability, to resolve 20 multiplet.
- Peak fitting results show that users can know the effect of spectrum analysis, which other commercial software can't.
- With a powerful automatic analysis ability, and customizable automatic the energy calibration.
- Standard source is not required for efficiency calibration.

Ⅱ. Applications

- It can be used for measurement of radioactivity in areas such as industry, scientific research, environmental protection, inspection and quarantine, disease prevention and control, as well as professional laboratories in colleges and universities, applicable to samples of various forms and substrate materials, including food radioactivity measurement, metal radioactivity measurement, measurement of radioactivity of building materials, radioactivity measurement of biological samples, aerosol sampling and measurement, nuclear science research and other fields.

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