ANGLE 5

User's Manual

Advanced Gamma-Spectrometry Software

Efficiency Calculations for Semiconductor and Scintillation Detectors

www.ortec-online.com
Tel. (865) 482-4411 ortec.info@ametek.com
801 South Illinois Ave., Oak Ridge, TN 37831-0895 U.S.A.
For International Office Locations, Visit Our Website

ORTEC® Part No. 931077
Manual Revision D

082022
Printed in USA

WARRANTY

ORTEC warrants that the items will be delivered free from defects in material or workmanship. ORTEC makes no other warranties, express or implied, and specifically NO WARRANTY OF MERCHANTABILITY OR FITNESS FOR A PARTICULAR PURPOSE.

ORTEC's exclusive liability is limited to repairing or replacing at ORTEC's option, items found by ORTEC to be defective in workmanship or materials within one year from the date of delivery. ORTEC's liability on any claim of any kind, including negligence, loss, or damages arising out of, connected with, or from the performance or breach thereof, or from the manufacture, sale, delivery, resale, repair, or use of any item or services covered by this agreement or purchase order, shall in no case exceed the price allocable to the item or service furnished or any part thereof that gives rise to the claim. In the event ORTEC fails to manufacture or deliver items called for in this agreement or purchase order, ORTEC's exclusive liability and buyer's exclusive remedy shall be release of the buyer from the obligation to pay the purchase price. In no event shall ORTEC be liable for special or consequential damages.

Quality Control

Before being approved for shipment, each ORTEC instrument must pass a stringent set of quality control tests designed to expose any flaws in materials or workmanship. Permanent records of these tests are maintained for use in warranty repair and as a source of statistical information for design improvements.

Repair Service

If it becomes necessary to return this instrument for repair, it is essential that Customer Services be contacted in advance of its return so that a Return Authorization Number can be assigned to the unit. Also, ORTEC must be informed, either in writing, by telephone [(865) 482-4411], or by facsimile transmission [(865) 483-2133], of the nature of the fault of the instrument being returned and of the model, serial, and revision ("Rev" on rear panel) numbers. Failure to do so may cause unnecessary delays in getting the unit repaired. The ORTEC standard procedure requires that instruments returned for repair pass the same quality control test that are used for new-production instruments. Instruments that are returned should be packed so that they will withstand normal transit handling and must be shipped PREPAID via Air Parcel Post or United Parcel Service to the designated ORTEC repair center. The address label and the package should include the Return Authorization Number assigned. Instruments being returned that are damaged in transit due to inadequate packaging will be repaired at the sender's expense, and it will be the sender's responsibility to make claim with the shipper. Instruments not in warranty should follow the same procedure and ORTEC will provide a quotation.

Damage in Transit

Shipments should be examined immediately upon receipt for evidence of external or concealed damage. The carrier making delivery should be notified immediately of any such damage, since the carrier is normally liable for damage in shipment. Packing materials, waybills, and other such documentation should be preserved in order to establish claims. After such notification to the carrier, please notify ORTEC of the circumstances so that assistance can be provided in making damage claims and in providing replacement equipment, if necessary.

TABLE OF CONTENTS

FIGURES

THIS PAGE INTENTIONALLY LEFT BLANK.

1. INTRODUCTION

1.1 WHAT IS ANGLE?

ANGLE is advanced quantitative gamma-spectrometry software. ANGLE has been in use for almost 30 years now in numerous gamma-spectrometry based analytical laboratories worldwide. It supports semiconductor (Ge) and scintillation (NaI) detectors. The vast majority of gamma-spectrometry systems in operation nowadays are built around these two detector types.

ANGLE allows for the accurate determination of the activities of gamma-spectroscopic samples, and thus is used for the **quantification** (i.e., spectrometry) of measurements. This is achieved by the calculation of **detection efficiencies** (see further), using the so-called "efficiency transfer" (ET) method. ET is a **semi-empirical approach**, which means that it is a combination of both experimental evidence and mathematical elaboration: detection efficiency for any "unknown" **sample** (and consequently its activity) can be determined by a calculation from the measurement of a **standard** source with a known activity (detector calibration). The two (standard and sample) do not need to match whatsoever – by shape, size, composition, container, or positioning vs. the detector – offering practically **unlimited flexibility, as well as substantial time saving and cost reduction** in application.

1.2 WHAT IS DETECTION EFFICIENCY?

A spectroscopic measurement implies a *radiation source* and a *radiation detector*. In the context of the present software, we deal primarily with radioactive (gamma-ray emitting) sources, as well as with sources emitting X-rays in a higher energy range. Appropriate photon detectors include both Germanium and Sodium-Iodide ones.

Only a fraction of the photons (gamma or X-rays) emitted by the source is captured by the nearby detector and hence recorded as a "spectrum" by the measurement device (multichannel analyzer), since:

- Photons are emitted from the source in all directions, only some of which travel towards the detector (geometrical solid angle)
- Out of those heading towards the detector, some are absorbed by the materials encountered on the way: the source itself, the container walls, the air layer between the source and the detector, detector cap, etc. (attenuation)
- Finally, not all of those reaching the detector's active body (the crystal) deposit their energy into it – some just pass through (detector response)

Some of the photons reaching the detector active body (the crystal) deposit only part of their energy into it. They do contribute to the spectrum but are of no interest in this context. Rather, we are interested in those which deposit all their energy, forming a "**full-energy peak**" in the spectrum.

Full-energy **detection efficiency** (ε_p) is then simply the ratio of the number of photons recorded in the full-energy peak (during the measurement, or "counting") to the number of all the photons of that energy emitted from the source (during the same time). In other words, it is the **probability** that a photon emitted from the source will be recorded as such by the detector. Apparently, ε_p is a function of photon energy.

1.3 WHY DETECTION EFFICIENCY MATTERS?

It is clear from the above that detection efficiency (ε_p) is essential for the **determination of source activity** (more precisely, the activity of a particular radionuclide), which is the goal of any gamma-spectrometric measurement. The total number of "counts" in the full-energy peak ("peak area", N_p) itself cannot provide this information. However, from the two combined (N_p and ε_p), the source activity is simply derived (see further).

In other words, in order to know the **actual source activity**, the measurement result (counts) itself is not enough to determine, or even to estimate the actual source activity – both detection efficiency and peak area have to be known to meet that aim.

Determining detection efficiency is, thus, **the key to quantitative gamma-spectrometry**. With this "gate open", the remaining part is rather elementary, or even trivial – incorporating some basic experimental evidence.

1.4 HOW TO DETERMINE DETECTION EFFICIENCY?

There are, in principle, three approaches to detection efficiency determination: **absolute**, **relative,** and **semi-empirical**.

Absolute methods are essentially mathematical and thus highly exact. However, they require extensive knowledge of a large number of physical parameters that characterize the detection process. High error propagation factors from the uncertainties on these parameters generally result in (unacceptably) poor accuracy of the computation result.

Relative method is the spectrometry classic. A source of known activity is compared with unknown one by employing **identical** counting arrangements. It is very accurate, but apparently not flexible at all to changing experimental conditions.

Semi-empirical methods combine the positive attributes of both the relative and absolute methodologies, simultaneously minimizing their drawbacks. Semi-empirical methods commonly consist of two parts: *experimental* (producing a reference efficiency characteristic of the detector – "calibration") and a *calculation* of ε_p. There are numerous variations within this approach.

1.5 HOW DO THE DIFFERENT APPROACHES TO EFFICIENCY DETERMINATION COMPARE?

There are *pros* and *cons* for each of the abovementioned approaches, depending on the purpose. Laboratory practice, however, has demonstrated that the semi-empirical methods – as is the case with ANGLE – represent the best compromise between the absolute and relative ones: while requiring less input parameters than the former, they offer much more flexibility than the latter.

Semi-empirical methods are less affected by input errors (due to uncertainties in detector parameters, for example), as their relative/experimental "halves" tend to reduce, or even cancel out, these errors.

2. WHAT IS NEW IN ANGLE 5?

ANGLE 5 brings grossly important new functionalities, providing not only for more accurate results, but also making work with ANGLE still easier and more intuitive.

2.1 CASCADE SUMMING CORRECTIONS

The most important improvement ANGLE 5 brings is the support for the correction of spectroscopic effects of true coincidence summing ("Cascade summing corrections", CSC). Namely, radionuclides decay in more or less complex ways ("decay schemes", or "transition cascades", or "cascades"), emitting (quasi)concurrent gamma-rays which populate various peaks in the spectrum (the latter being collected/created by the counting device). Hence a peak may be populated by more than one transition. This effect is called cascade summing or true coincidence summing.

For a given peak, originating from a characteristic gamma transition (gamma line) of interest, this may lead to either addition or loss of (expected) counts, anyhow "spoiling" the peak in analytical sense. Accounting for this effect represents the cascade summing correction (CSC). Calculation of CSC factors is, in principle, a pretty elaborate task. It is based on the knowledge of decay schemes of the nuclides of interest and detection efficiencies for the given counting arrangement. CSC factors do not depend on the source activity (as is the case, to the contrary, with random coincidences).

Cascade summing effects tend to diminish with increasing distance between the source and the detector, and become more prominent for close geometries (e.g., for "contact" measurements, or for Marinelli sources, or for well-type detectors), and can amount to tens of percent. As close geometries are practically obligatory for low activity measurements (most notably in environmental monitoring), the importance of proper CS corrections cannot be overestimated.

2.2 MONTE CARLO CALCULATIONS

Starting with this version, ANGLE is replacing numerical integration with Monte Carlo method. This new approach is an important step we made in order to enable certain features, such as cascade summing corrections. Switching to Monte Carlo calculations allows more flexibility in developing various future improvements of the software.

2.3 CALCULATION PRECISION

Now it is possible to set the desired precision for the calculations more exactly. Users can define the calculation precision in percentages, instead of *Gauss coefficients*, which were used previously, and which were not very familiar to many users.

2.4 NEW DATA FORMATS

Now it is possible to export the calculation results to JSON and YAML formats. Support for these popular human-readable file formats for data interchange, apart from the XML format introduced with ANGLE 4, will enable easy integration with even more third-party applications.

2.5 NEW IMAGE FORMATS

The two popular graphics formats are added to the list of supported formats for exporting previews: PNG and SVG. PNG format is a lossless raster format, and the SVG is vector format, both widely used in the desktop, mobile and web applications.

3. INSTALLATION

The installation procedure of ANGLE 5 is simple and quick. First, in the welcome screen you need to choose the language which will be used in the installation procedure.

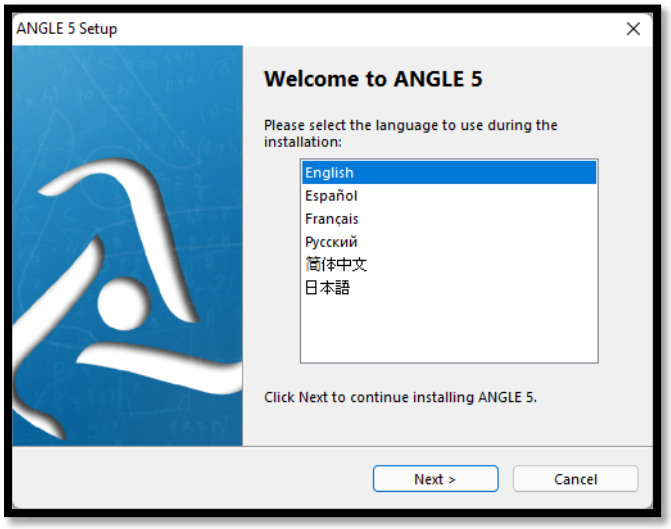

Figure 1. Language Selection

The installation will continue using the selected language. This language will also be set as the default language for ANGLE 5. Click the "**Next**" button to continue.

The language chosen during the installation process will be used in ANGLE by default, but you will be able to switch ANGLE to another available language at any time.

The next dialog box is the Software License Agreement to review. Accept it by clicking the radio button in the bottom of the screen and click the "**Next**" button to continue.

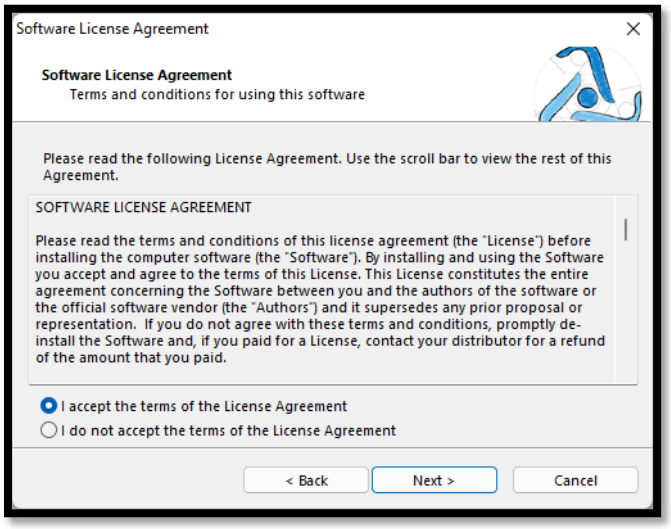

Figure 2. Software License Agreement

In the following dialog box, you can choose user settings. First, choose whether you want to install ANGLE 5 for the current user only (the recommended option), or for all users on the system.

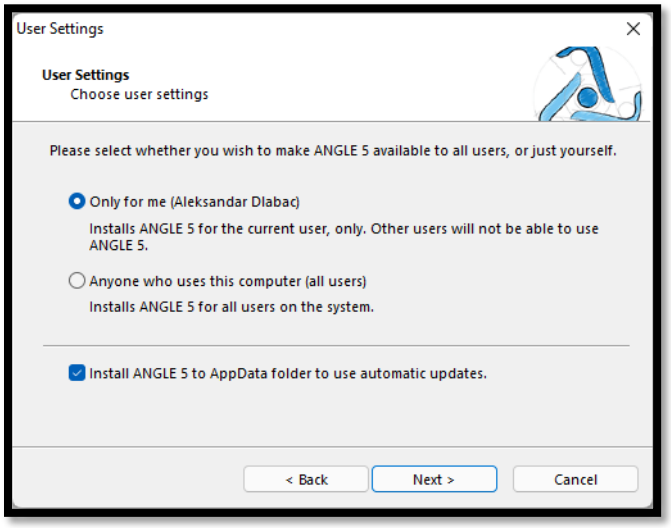

Figure 3. User Settings

You can also choose if you would like to install ANGLE 5 to the *AppData* folder on your system. The installation to the *AppData* folder is recommended for seamless updates of the software in the future. Otherwise, depending on the operating system used, you will need to provide administrator rights each time you want to update ANGLE.

Click "**Next**" button to continue.

If choose not to install Angle in the AppData folder, Angle 5 will be installed in the "Program Files" folder ("Program Files (x86)" of 64-bit operating systems). This will require administrator rights to both install Angle and to update it later.

In case you choose installation to AppData folder for all users, you will need administrator rights for installation, but not for updates.

For recommended user settings (current user and AppData folder), no administrator rights are required either for installation or for future updates.

In the final step you can choose if you would like to have an icon for ANGLE 5 on your desktop.

If the installation program detects that the previous version of ANGLE is already installed on your system, you will be also offered the option to import those files to ANGLE 5.

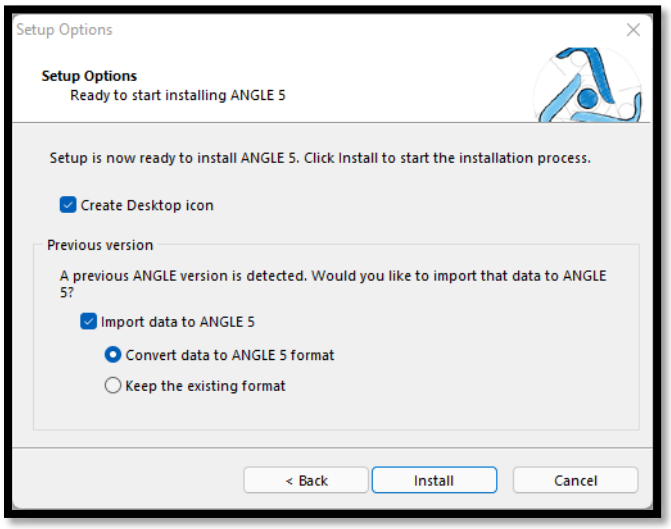

Figure 4. Setup Options

Even if you choose not to import the data, you will be able to use them later, but importing will make them more easily accessible.

If you choose to import the data from the existing ANGLE installation, you can choose whether you would like to convert the data to the *new file format*, introduced in ANGLE 5, or to simply copy the files to new location. You will be able to use the files in both the new and old formats, but in that case you will lose out on flexibility regarding some advanced options.

You can find out more about the new file formats and its advantages in the Appendices B (Command Line Parameters) and C (File Formats).

Click the "**Install**" button to start the installation. After the installation is complete, you will be able to choose whether you would like to launch the newly installed ANGLE 5 upon a click on the "**Finish**" button, or not.

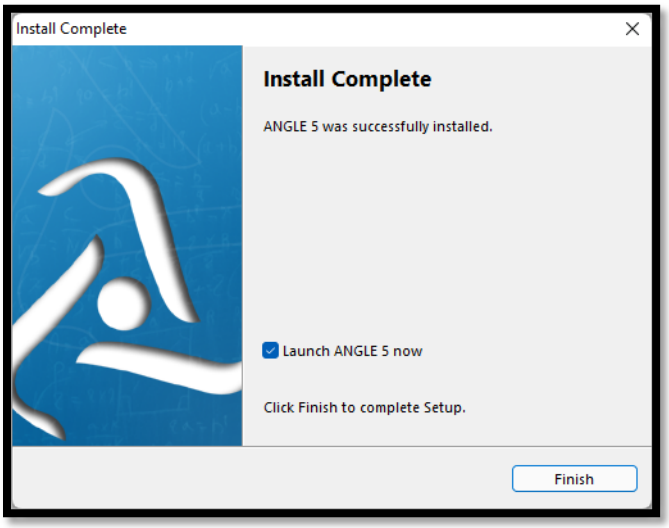

Figure 5. Finishing the Installation

3.1 USING THE INSTALLATION PROGRAM TO UPDATE ANGLE

If you already have ANGLE 5 installed on your computer, when you run the installation program, there will be no need to choose the installation options, since you already did this the first time. The update will automatically start after clicking the "**Next**" button on the welcome screen.

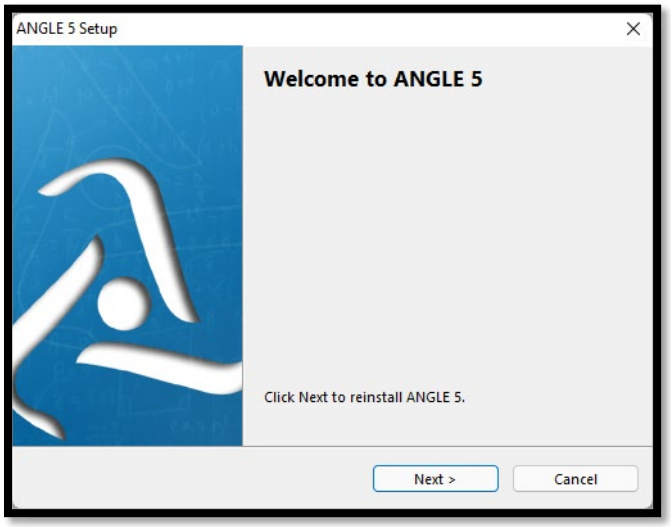

Figure 6. Updating ANGLE

4. REGISTRATION

After the initial installation, ANGLE will work in **demo mode**. In this mode the software is fully functional, except that the calculations can only be performed with the **demo detectors** that come with ANGLE 5.

After obtaining the ANGLE license, you will be provided with the serial number needed to register the software and to unlock unlimited calculations.

Each time you reinstall your computer ANGLE must be registered in order to be fully operational. The number of registrations for each copy of ANGLE is limited to three per one year. Do not disclose the serial number to other parties to prevent yourself from being unable to register your copy when needed.

You can open the registration form simply by clicking on the "**Register ANGLE 5**" button from the "**Help**" ribbon tab.

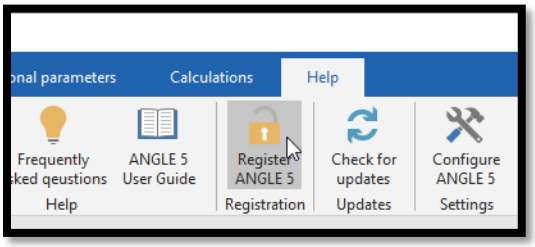

Figure 7. Registration Button

The registration form consists of the following fields:

- Name*
- Company*
- Address* (two lines)
- City*
- ZIP/postal code
- Country*
- Telephone
- Email
- Serial number*
- Authorization key

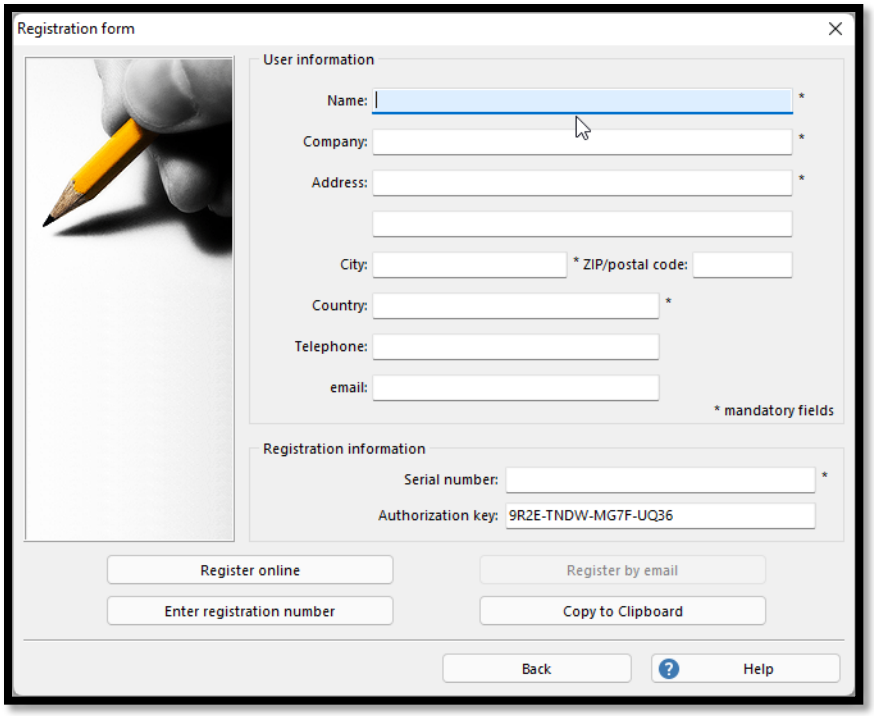

Figure 8. The Registration Form

Mandatory fields are marked with the asterisk ("*").

The **Serial number** field must be completed with the valid ANGLE serial number obtained from the software distributor.

The **Authorization key** is calculated by ANGLE, and it cannot be modified.

There are two ways to register ANGLE:

- Online registration
- Registration by email

If your computer is connected to the internet, registration can be completed in a few seconds simply by clicking the "**Register online**" button.

The second method of registering is by email. By clicking on "**Register by email**", ANGLE will automatically create an email for you with all registration parameters. After receiving your email, we will send you back the unique registration number which will unlock your copy of the software. To enter the received registration number, click the "**Enter registration number**" button on the registration form and enter the registration number you received.

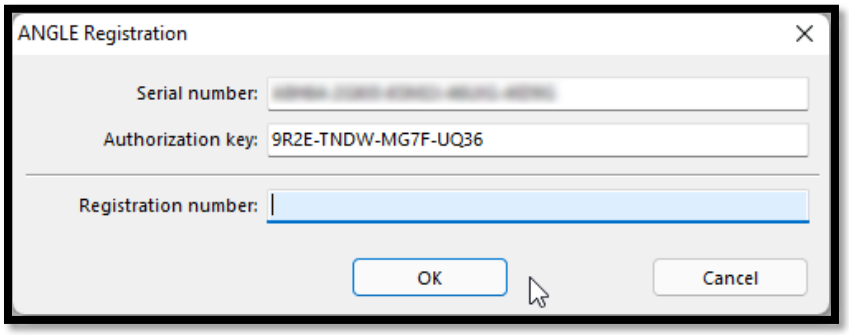

Figure 9. Registration Number Entry

We suggest you copy the received registration number and paste it to the appropriate field, in order to avoid typing mistakes.

Registration information can be copied to your Clipboard by clicking the "**Copy to Clipboard**" button and pasted to other applications (text editor, or word processing software, for example). This can be convenient when sending the registration information from another computer.

THIS PAGE INTENTIONALLY LEFT BLANK.

5. USER INTERFACE

ANGLE has an intuitive graphical user interface. It consists of six parts – the ribbon at the top of the window and five principal data groups arranged as frames in the **main ANGLE window**, as shown in the following figure.

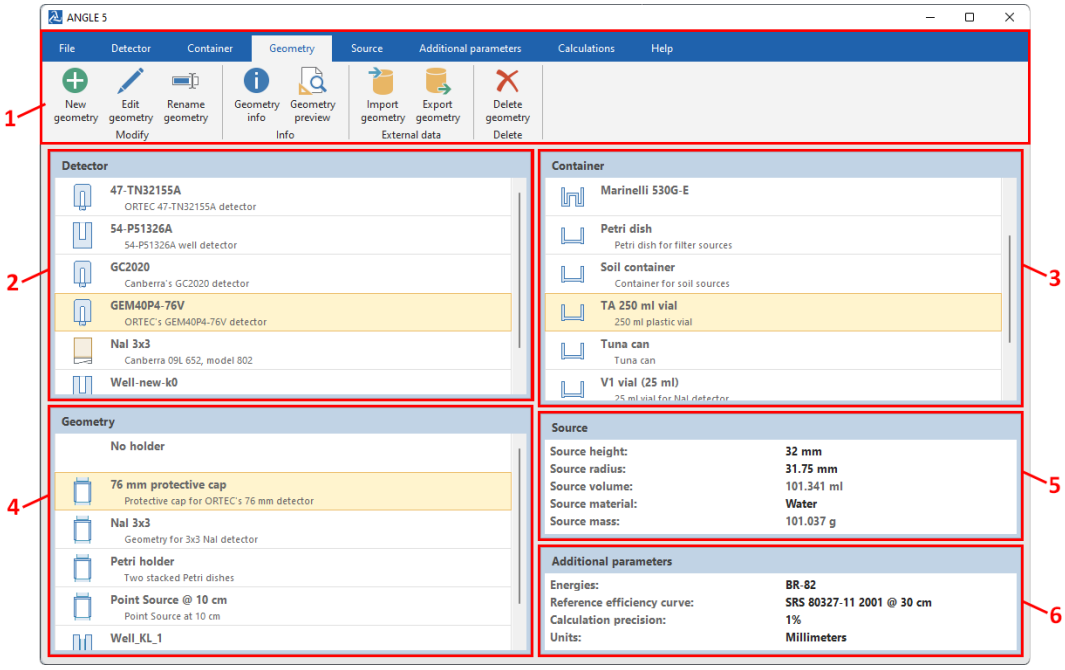

Figure 10. ANGLE Main Window

1. **Ribbon** – replaces the classic application's main menu. This makes usage of ANGLE faster and easier, while maintaining the functionality of the main menu. The ribbon consists of eight tabs: *File*, *Detector*, *Container*, *Geometry*, *Source*, *Additional parameters*, *Calculations* and *Help*.
2. **Detector** frame – contains an alphabetically sorted list of all detectors defined in ANGLE. Each detector is labelled with its name and description. Detector icons in the left-hand part of the list display one of the eight possible detector types.
3. **Container** frame – contains an alphabetically sorted list of all containers defined in ANGLE. Each container is shown with its name and description. Container icons in the left-hand part of the list show one of the two possible container types. The "No container" option is at the top of the list.
4. **Geometry** frame – contains an alphabetically sorted list of all geometries defined in ANGLE. "Geometry" here means the geometrical positioning of the source vs. the detector, including source support (the "holder"). Each geometry is shown with its name and description. Icons in the left-hand part of the list represent one of three possible geometry types (for well detector, for Marinelli geometry or for other detector/geometry types). The "No holder" option is at the top of the list.
5. **Source** frame – contains information about the radiation source used for calculations (height, radius, volume, material, and mass).

6. **Additional parameters** frame – contains the remaining calculation parameters: the set of energies of interest, the reference efficiency curve, the calculation precision, and preferred units of length (millimeters, centimeters, or inches).

If you keep the mouse pointer over any button on a ribbon for a short time, the hint for that button will appear with a brief description of the functionality of the button.

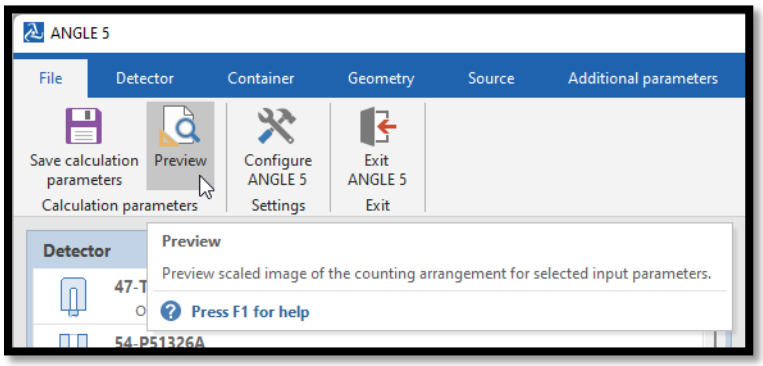

Figure 11. Hint for a Button

6. THE HELP SYSTEM

At any moment, the built-in help system is available for you – simply press the **F1** key. The Help System is context sensitive, which means that the help provided by the system is dependent on the specific action you are performing at the time. For example, if you press **F1** key while entering detector data, a help for the detector data entry will be automatically displayed.

You can, also, display the help contents by choosing the tab "**Help**" from the ANGLE ribbon and then clicking the "**Help contents**" button.

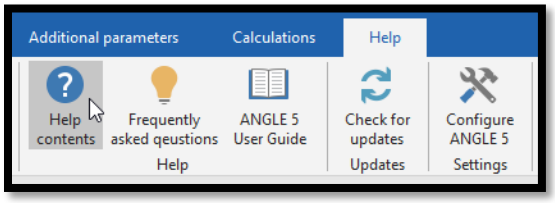

Figure 12. Help Contents Button

The help window is shown in the next figure. On the left-hand side, in the "**Contents**" tab, is the hierarchical list of all help topics. Click on any item in the list to get the appropriate help text.

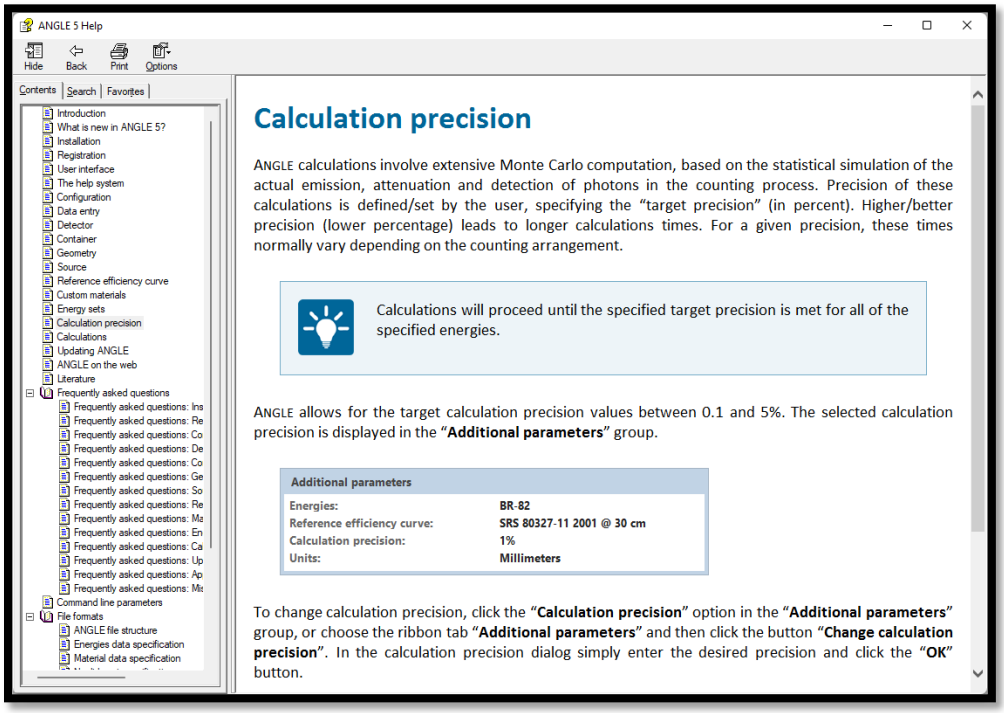

Figure 13. Help Window

You can, also, search help using the "**Search**" tab, or view and add pages to favorites using the "**Favorites**" tab.

Help also contains an exhaustive list of frequently asked questions that we have compiled during the years of interaction with our users. You can see the "**Frequently asked questions**" section directly

from the main screen with just one click. To do this, simply click on the "**Frequently asked questions**" button, which is located next to the "**Help contents**" button on the "**Help**" tab.

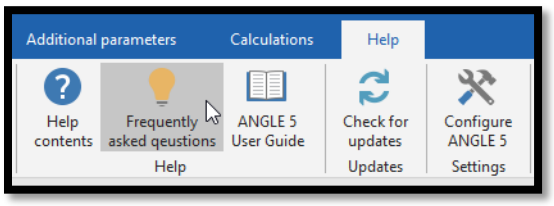

Figure 14. Frequently Asked Questions Option

Next to the "**Frequently asked questions**" button you can find the "**ANGLE 5 User Guide**" button, which opens the User Guide in PDF format.

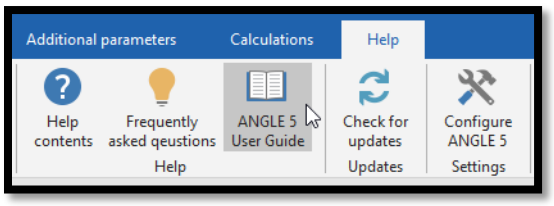

Figure 15. User Guide Option

7. CONFIGURATION

To configure ANGLE 5 to best suit your needs, choose the tab "**Help**" from the ANGLE ribbon and then click the "**Configure ANGLE 5**" button.

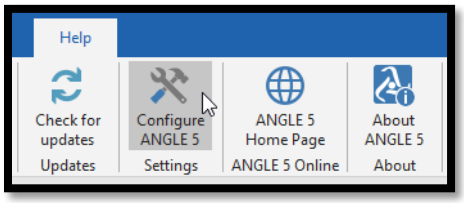

Figure 16. Configure ANGLE 5 Option

In the configuration dialog box, you can configure:

- Units of length
- Language
- Location of ANGLE files
- Progress bar on Windows Taskbar
- Connectivity options

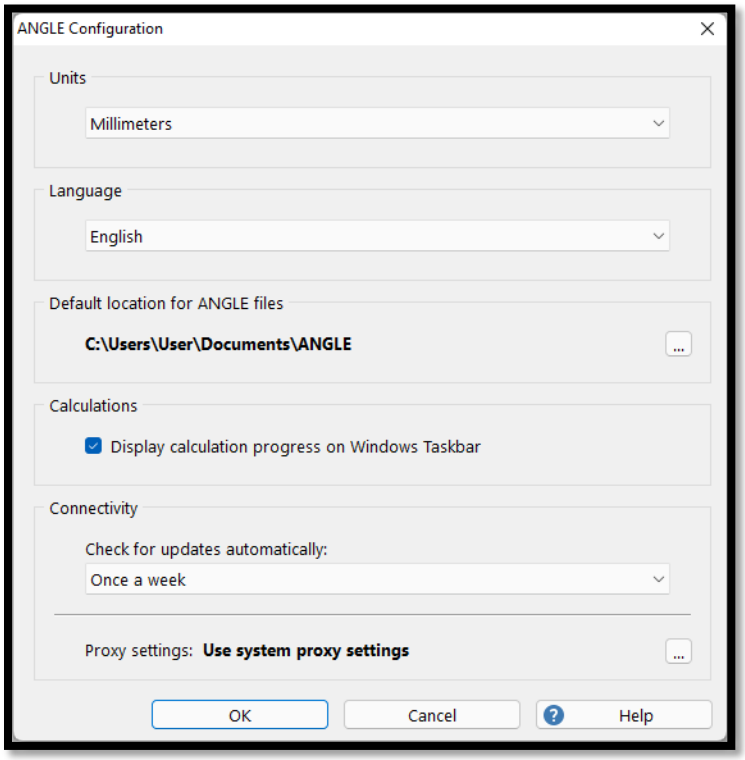

Figure 17. Configuration Dialog Box

ANGLE can be used with millimeters, centimeters, and inches as **units of length**. You can switch between units by choosing one of these units from the drop-down list.

The **Language** drop-down list contains the list of available languages for the ANGLE user interface. You can change it simply by choosing a new language from the list.

By default, **ANGLE files** are saved to the "ANGLE" folder, which is located in the user's *Documents* folder. These files are calculation parameters files, calculation results files, energies files, material files, and reference efficiency curve files. Each of these types will be saved in an appropriate sub-folder under the folder "ANGLE", mentioned above. This default location can be changed by clicking on the ellipsis button in the right-hand side of the "**Default location for ANGLE files**" group.

On Windows Vista and newer operating systems, ANGLE can also display the **calculation progress on the Windows Taskbar**. This is useful in case when running many calculations at once, so you can monitor the progress of calculations while working with other applications, even if the ANGLE window is not visible. This option can be enabled or disabled by (un)checking the "**Display calculation progress on Windows Taskbar**" check box.

Figure 18. Calculation Progress on Windows Taskbar

The last group on the Configuration dialog box is used to configure the **connectivity** options. From the drop-down list, you can choose how often you would like ANGLE to automatically check for updates. Possible options are: "once a day", "once a week" and "never". Regardless of the option used, it is possible to manually check for updates at any time.

Depending on the internet connection you are using on your computer, it might be necessary to change the setup of the proxy server. ANGLE will, by default, use the proxy parameters defined in the system. By clicking on the ellipsis button in the lower-right corner you can override these settings, as shown in the figure:

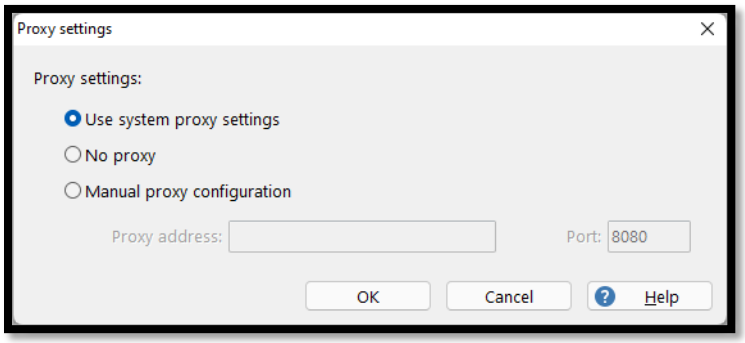

Figure 19. Proxy Settings

From here, you can choose whether you want to use proxy settings defined in your operating system, use no proxy server, or to manually enter the address and port values of your preferred proxy server.

8. DATA ENTRY

In order to perform calculations in ANGLE, you need to specify a number of parameters for the specific measurement. The process usually starts with entry of the data defining the detector, container and geometry used for calculation.

Real numbers can be entered in exponential form. For example, 5.43 · 10-3 can be entered in two ways: as 0.00543 or 5.43E-3. This is very useful when entering very small numbers, for example 1E-7 (1 · 10-7) is more convenient than 0.0000001.

When entering the data, you can move from one text field to another by mouse click or by pressing either the **Tab** or **Enter** key. This way you can enter values much faster, especially when using the numeric keyboard.

By pressing the Enter key, while the cursor is in the last field of one group/tab (e.g., Contact pin material field in the Detector tab), the next tab will be displayed automatically, so that data entry can be continued without the need to select the next tab and data field by mouse. Thus, pressing the Enter key after each data entry is the easiest way to continue entering and/or editing data.

During data entry the currently selected field is emphasized with a light blue background.

All fields representing units of length are trailed by the unit abbreviation (e.g., “mm”). This helps avoid making wrong entries in cases when dimension units are changed.

You can change the units of length in the configuration dialog box. To open it, click on the “Configure ANGLE 5” button, which you can find under the “File” and “Help” ribbon tabs.

The windows for detector, container or geometry parameters entry show schematic drawings on the right-hand side. These drawings are very helpful during the data input process. While you are entering certain dimensions, a red dimension line is displayed on the illustration indicating the required parameter (see the next figure). This visual aid is very important both to help you enter the data faster and to avoid errors.

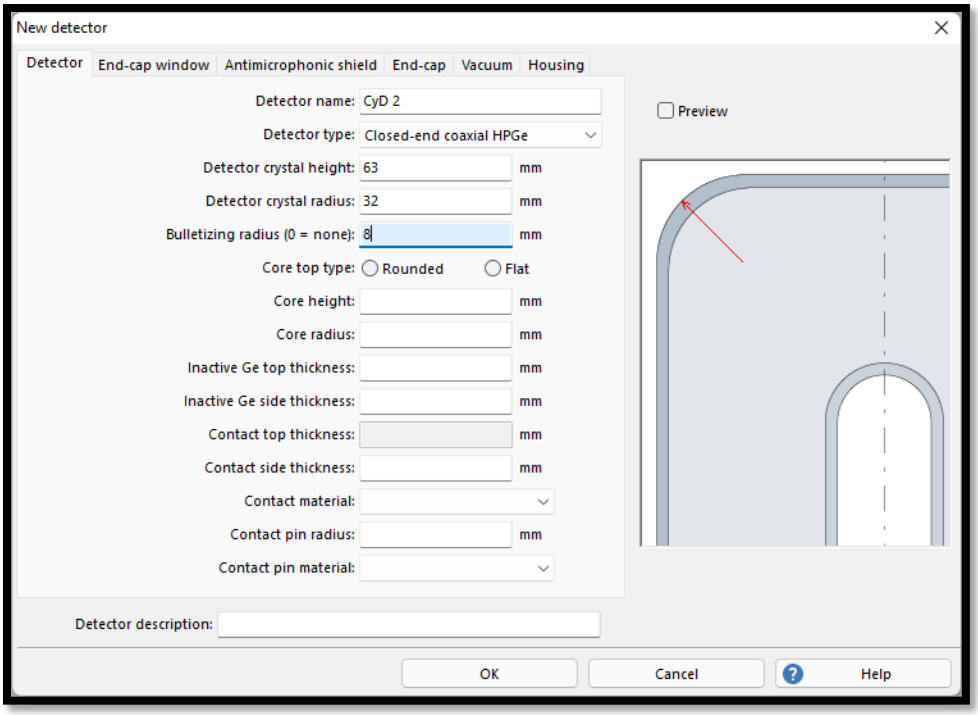

Figure 20. Data Entry

The terminology used by different manufacturers is different and sometimes even ambiguous. Thus, keeping an eye on the illustration markings during data entry is advisable to understand the terminology used in Angle and to avoid mistakes.

8.1 MATERIALS

Materials (materials' chemical composition) of certain construction elements can be selected from the appropriate drop-down list. This list contains the most common materials for the given parameter. For example, when choosing the material for a detector end-cap, Aluminum, Magnesium and Carbon fiber are offered as the most common materials for it.

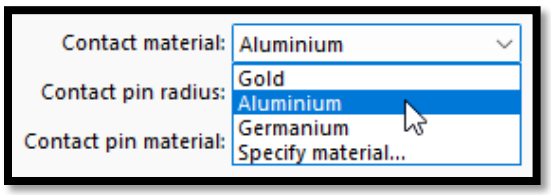

Figure 21. Choosing the Material

If the desired material is not in the list, click on the "**Specify material...**" item in the drop-down list, and you will be able to define any material, as long as you know its composition. You can find more details about defining new materials later, in the "**Custom materials**" section.

8.2 PREVIEWS

One of important new features of ANGLE 5 is the preview option. Through this you can see a scaled image of the detectors, containers, geometries, and even complete counting arrangements.

You can see the preview image by choosing some of several preview options on the ribbon, or pop-up menus, and while entering or changing the parameters for detector, container, or geometry.

The next figure shows the preview window of one detector.

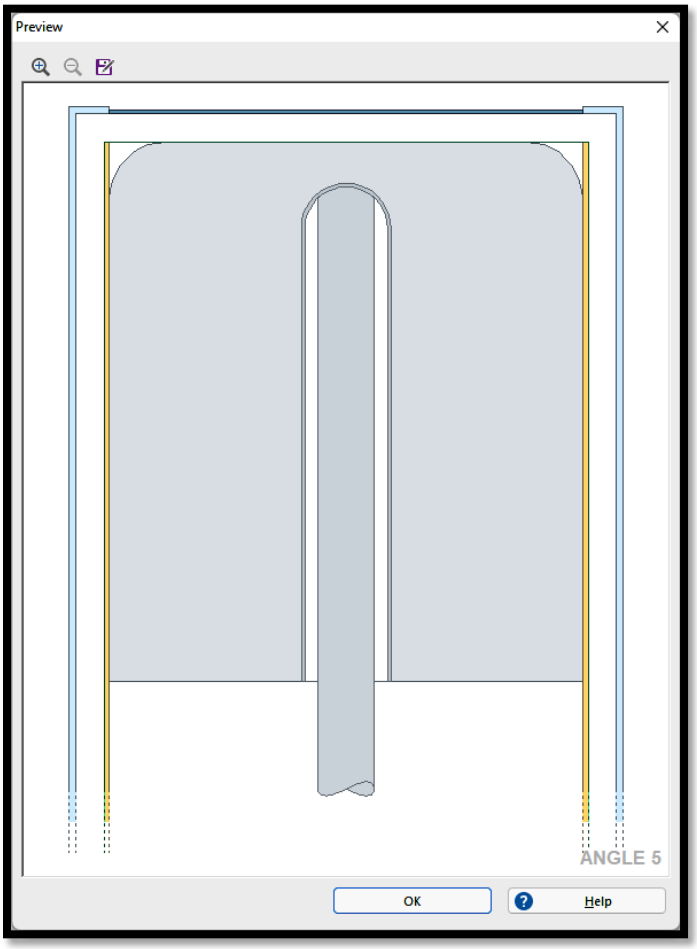

Figure 22. Detector Preview

Above the preview image you can find three buttons:

- Zoom-in button
- Zoom-out button
- Save button

If the image is zoomed-in so it cannot fit the window completely, you can pan it simply by dragging it with the mouse. This way you will be able to see and examine even smaller details.

The save button will let you save the preview image so you can use it in another application, for instance word processing software. You can choose between two raster and two vector formats:

- Raster formats: **PNG**, **JPEG** and **BMP**
- Vector formats: **SVG**, **WMF** and **EMF**

The vector formats consume much less space on a disk, and you can scale them without losing any quality. They are an ideal choice for printing. You can even import them to vector graphics applications such as *Adobe Illustrator* or *CorelDRAW* and edit them freely.

Raster images may look better on screen and other low-resolution devices and are an ideal choice for the web. Raster images will be saved using the selected zoom factor, so the more you zoom it, the larger resulting image will be.

8.3 IMPORTING AND EXPORTING PARAMETERS

Another new feature in ANGLE 5 is the possibility of importing and exporting parameters for easy sharing. For example, you can export the detector parameters and import them to another computer with ANGLE 5 software installed, to avoid re-typing the parameters and the possible mistakes caused by this.

You can use the buttons on the ribbon or options in the pop-up menus for detector, containers, or geometries to select the file you are exporting to or importing from.

You can also import data from the calculation parameter files and the calculation results files, since they contain all types of parameters. From the file selection dialog, simply choose the type of file you want to import the data from. In the same way you can import parameters for detectors, containers, geometries, reference efficiency curves and energies.

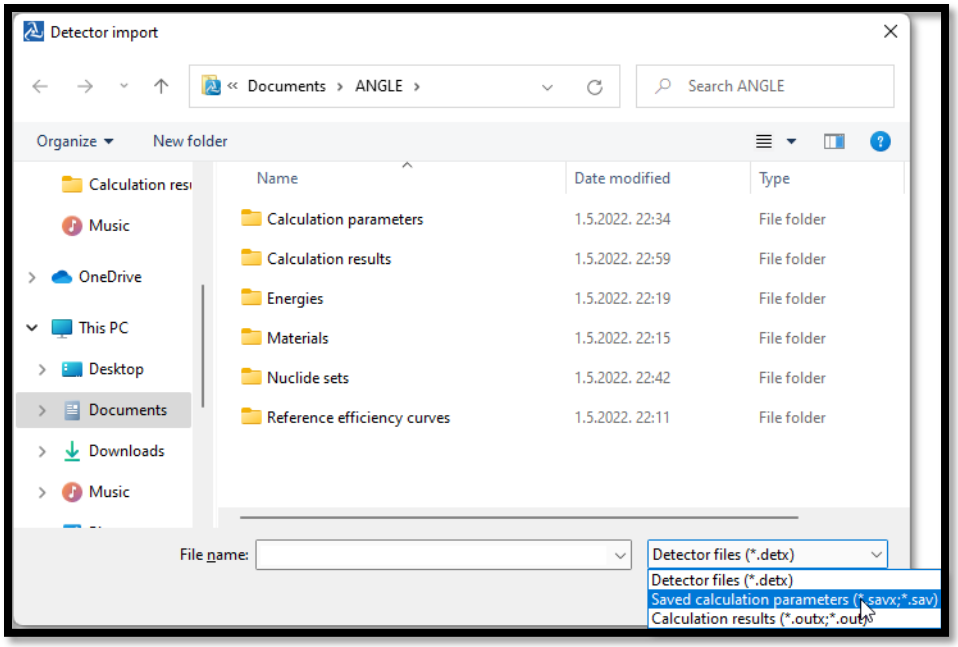

Figure 23. Choosing the Type of File for Import

It is also possible to import data from calculation parameter files and calculation results files from the previous version of ANGLE.

9. DETECTOR

Specifying the detector data is a crucial part of efficiency calculations. In ANGLE you can define an unlimited number of detectors of any type the software supports (see further). You can enter parameters for all detectors in your lab and use them, without any limitations.

All your detectors will be displayed in an alphabetically sorted list (figure **Error! Reference source not found.**).

9.1 DEMO DETECTORS

Demo detectors are a new feature of ANGLE 5 – it now comes with a set of eight predefined demo detectors, one for each supported type. The demo detectors can be used for calculations **even in demo mode**, that is, even if ANGLE is not yet registered. This enables users to run calculations and evaluate the results, so as to become more familiar with the scope of the software and its capabilities without/before being registered.

Demo detectors are also very useful for educational/training purposes. Now ANGLE is there for everyone as a **free educational/training tool**. For example, it can be used for studying the impact of particular parameters characterizing the detection process on the detection efficiency; or, just to experience/train gamma-spectrometry practice.

Demo detectors are read-only, so their parameters cannot be altered, but you are able to delete them.

Once deleted, it is not possible to restore a demo detector back to the list, and you will lose the possibility of using that detector again in the future. Be careful if you are using an unregistered version of Angle since you will lose the calculation possibilities for any deleted demo detector.

9.2 DETECTOR DATA ENTRY

The options for detector manipulation are located in the "**Detector**" tab on the ribbon.

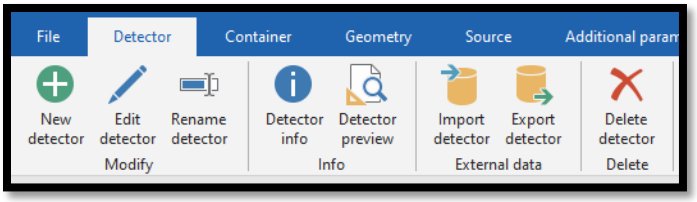

Figure 24. "Detector" Ribbon Tab

In total, there are eight buttons:

- **New detector** – to create a new detector
- **Edit detector** – to change the parameters of the already existing detector
- **Rename detector** – to rename the detector
- **Detector info** – to display the parameters of a detector

- **Detector preview** – to display a scaled preview image of a detector
- **Import detector** – to import a detector from a file
- **Export detector** – to export a detector to a file
- **Delete detector** – to delete a detector

The alternative way is to use the pop-up menu with the same options, which you can open by right-clicking the list of detectors.

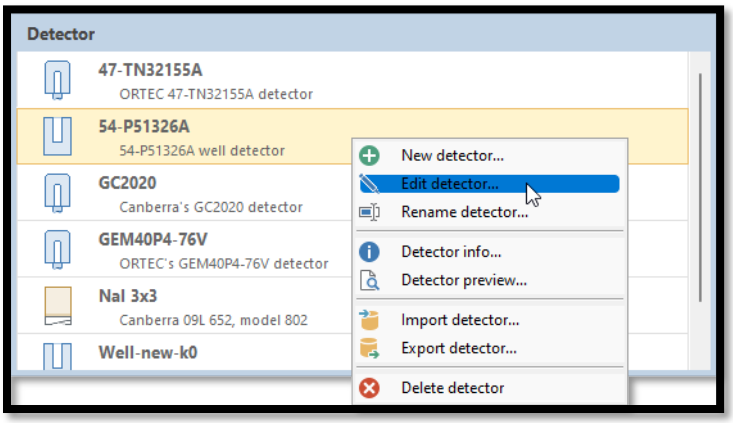

Figure 25. Detector Pop-up Menu

When defining a new detector, first you have to type in its name, and to choose the type of your detector. There are eight detector types available:

- Closed-end coaxial HPGe
- True-coaxial HPGe
- Closed-end coaxial Ge(Li)
- Open-end coaxial Ge(Li)
- Planar LEPD
- Well
- NaI
- NaI Well

"Closed-end coaxial HPGe" encompasses both n-type and p-type closed-end coaxial detectors, as well as thick planar detectors with crystal hole.

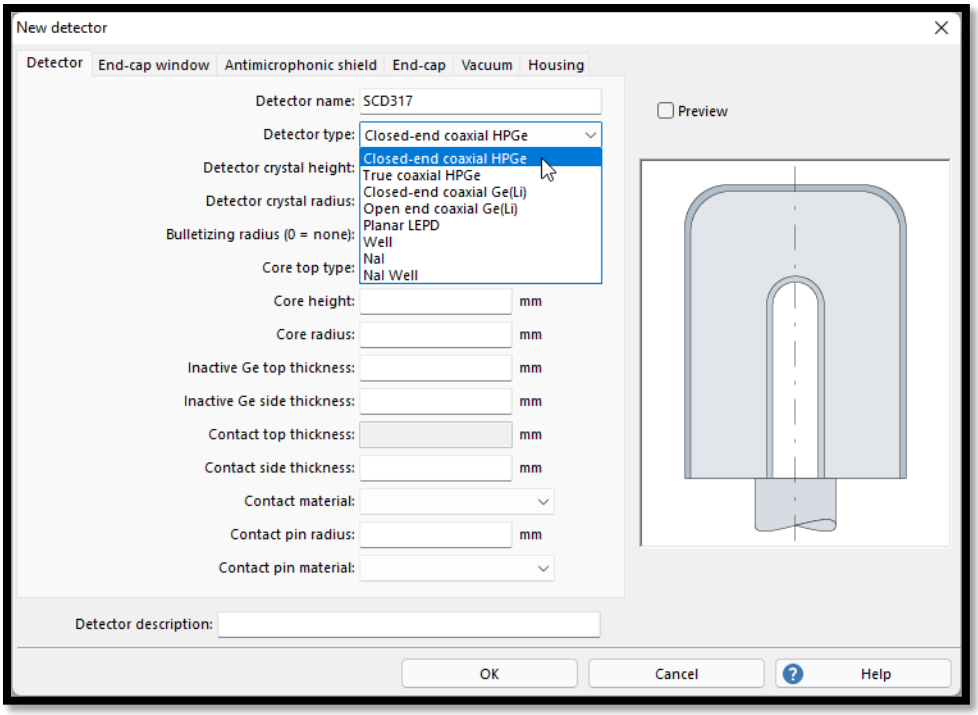

Figure 26. Choosing the Detector Type

Depending on the detector type chosen, the appropriate set of parameters for the given detector type will be displayed. Data fields are divided into six groups (four in case of well detectors), each one represented by a tab:

- **Detector** (data for the detector crystal)
- **End-cap window**[1] (data for the end-cap window, if any)
- **Antimicrophonic shield** (data for the antimicrophonic shield, if any)
- **End-cap** (detector end-cap data)
- **Vacuum** (data about the vacuum between the end-cap and detector crystal)
- **Housing**[1] (detector housing data)

The next figure shows the detector data entry window, with the preview image on the right-hand side and a red dimension line indicating the parameter being edited (detector radius).

[1] This group does not exist for well-type detectors (not applicable or being irrelevant for efficiency calculations).

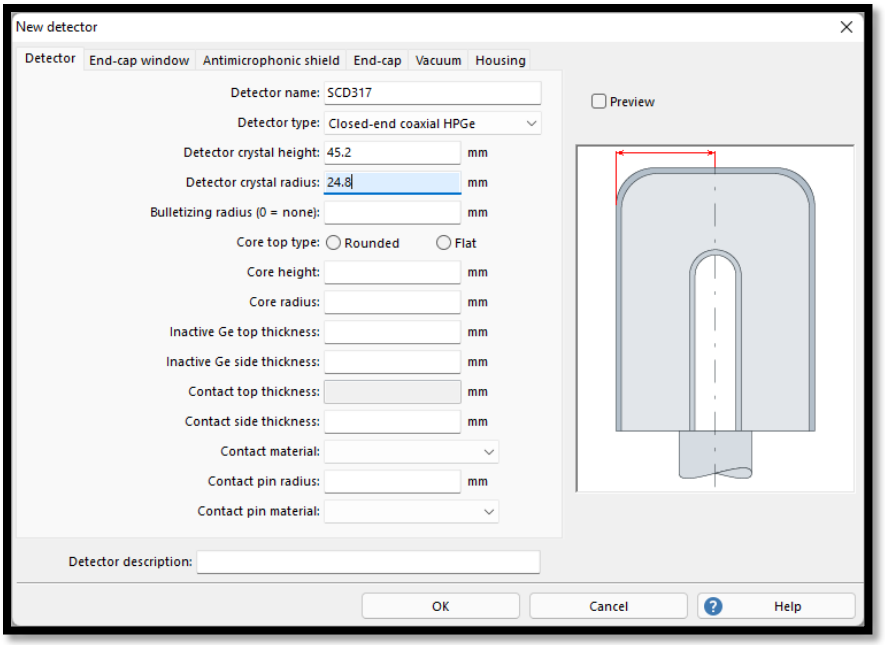

Figure 27. Detector Data Entry

Above the illustration you can find a "**Preview**" check box. You can check it to see the scaled preview, instead of the generic illustration. The image is proportional, which is useful for noticing any made blunders in parameter entries, which would otherwise be hard to detect.

Although useful and practical, "Preview" functionality is not aimed at, and does not explicitly detect all input errors!

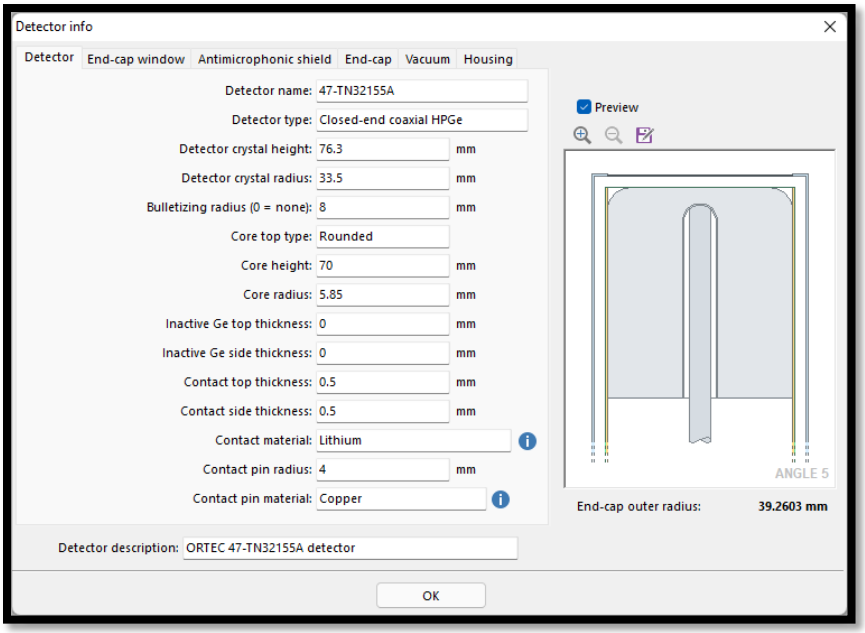

Figure 28. Detector Preview

You can zoom-in and zoom-out the preview image, pan it and export it to various raster and vector graphics formats (read more in "**Data entry**" section).

To be able to see the preview image, all dimensions must be entered. Otherwise, the preview cannot be generated.

If you check the **end-cap window** or **antimicrophonic shield** options, additional tab(s) will be displayed, as well as the additional fields, so their dimensions and materials can be specified.

Depending on whether the antimicrophonic shield exists or not, the number of fields needed to be entered under the Vacuum tab will be different.

If your detector's end-cap is coated with some material(s), you can define up to two coating layers. Each coating layer can be of a different material and its thicknesses can be defined separately for end-cap top and side.

Once all parameters are defined, Angle will calculate and display the detector end-cap outer radius. You can use this value to re-check if you entered the data correctly. This is a well-known parameter (also easily measurable), while in Angle it is obtained as the sum of several separate (inner) detector parameters.

THIS PAGE INTENTIONALLY LEFT BLANK.

10. CONTAINER

Radioactive sources are most often measured while placed in containers. It is important to specify the container holding the source, since it represents an absorbing layer and, thus, attenuates the gamma-rays on their way to the detector. In ANGLE you can define an unlimited number of containers.

If the source is not in a container (e.g., stand-alone pill sources), then the container data does not have to be entered. Instead, simply choose the option “No container” in the “Container” box on the main screen.

All your containers will be displayed in an alphabetically sorted list (Figure 10).

10.1 CONTAINER DATA ENTRY

The options for container manipulation are located in the “**Container**” tab on the ribbon.

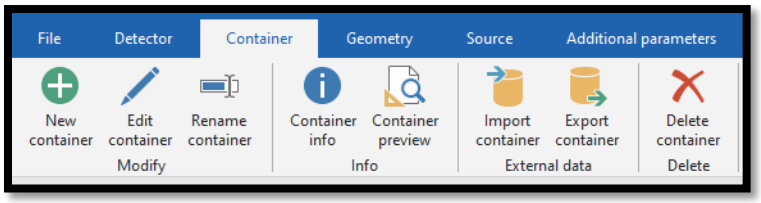

Figure 29. “Container” Ribbon Tab

There are eight buttons within this tab:

- **New container** – to create a new container
- **Edit container** – to change the parameters of the already existing container
- **Rename container** – to rename the container
- **Container info** – to display the parameters of a container
- **Container preview** – to display a scaled preview image of a container
- **Import container** – to import a container from a file
- **Export container** – to export a container to a file
- **Delete container** – to delete a container

The alternative method is to use the pop-up menu with the same options, which you can open by right-clicking the list of containers.

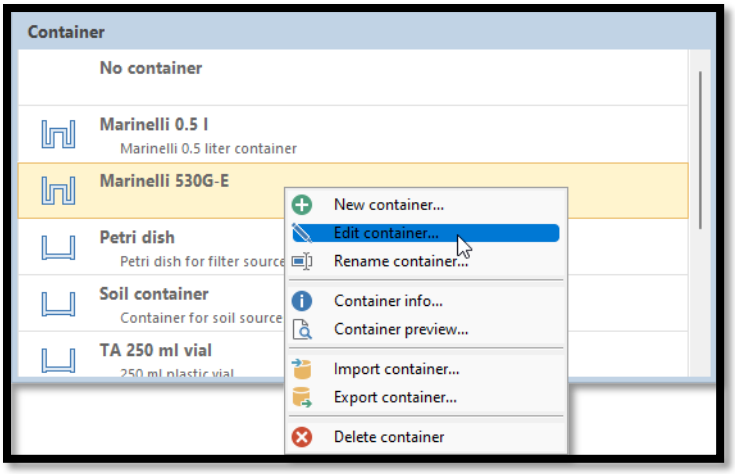

Figure 30. Container Pop-up Menu

When defining a new container, first you have to type in its name, and to choose the type. There are two container types available:

- Cylindrical
- Marinelli

Depending on the container type, its parameters will vary. The next figure shows the container data entry window, with the preview image on the right-hand side and the dimension line indicating the parameter being edited (container inner radius).

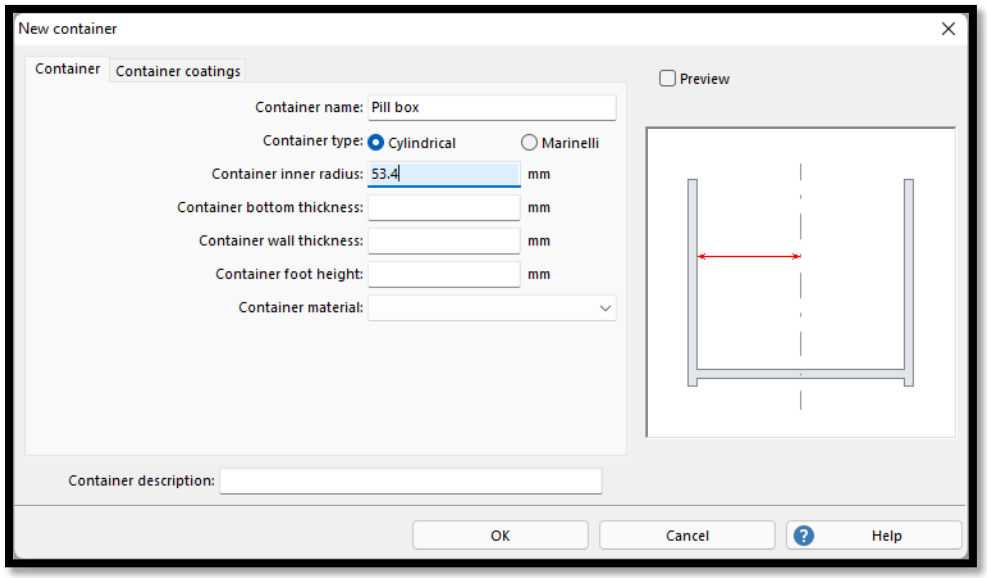

Figure 31. Container Data Entry

The first tab contains the information about the container itself, while the second tab contains the information about the inner coating layers. Up to two coating layers are supported. Each coating layer can be of a different material and its thicknesses can be defined separately for container side(s) and bottom(s).

Above the illustration you can find a “**Preview**” check box. You can use it to see the scaled preview, instead of generic illustration. The image is proportional, which is aims to assist in identifying any obvious mistakes made in entering the parameters, which would otherwise be hard to detect.

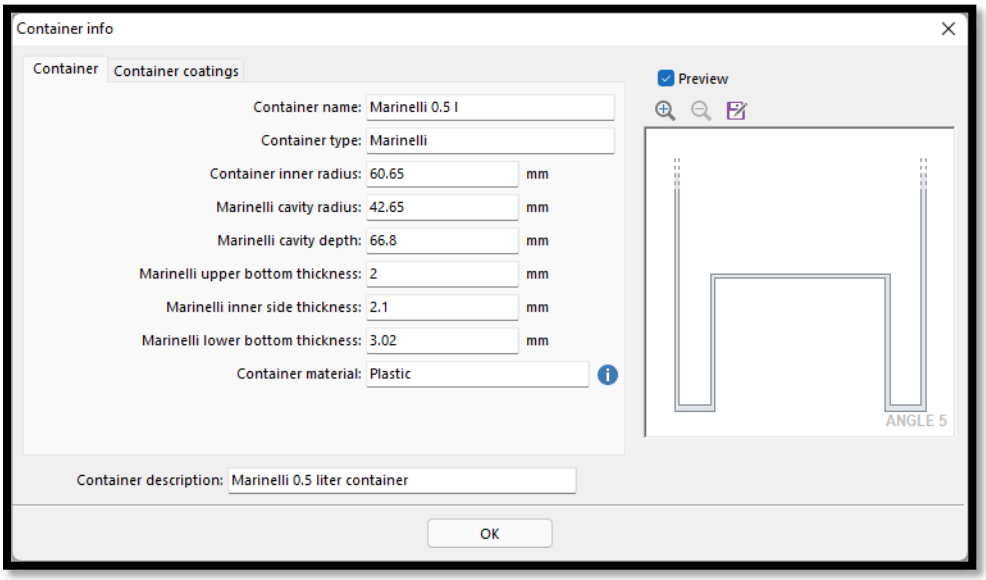

Figure 32. Container Preview

You can zoom-in and zoom-out the preview image, pan it and export it to various raster and vector graphics formats (read more in the “**Data entry**” section).

To be able to see the preview image, all dimensions must be entered. Otherwise, no preview can be generated.

THIS PAGE INTENTIONALLY LEFT BLANK.

11. GEOMETRY

Geometry (or *counting geometry*) defines the source/container holder (support), and additional absorbing layers (if any). Radioactive sources are usually positioned on some sort of a holder which ensures that the source remains in a set position versus the detector during the measurement. It is important to specify this precisely, including any other absorbing layer between the source and the detector. In ANGLE you can define an unlimited number of geometries.

If there is no holder and there are no additional absorbing layers (e.g., the source/container is placed directly on the detector end-cap), you do not need to specify the geometry data. Instead, simply choose the option **"No holder"** in the **"Geometry"** box on the main screen.

All your geometries will be displayed in an alphabetically sorted list (Figure 10).

11.1 GEOMETRY DATA ENTRY

The options for geometry manipulation are located in the "**Geometry**" tab on the ribbon.

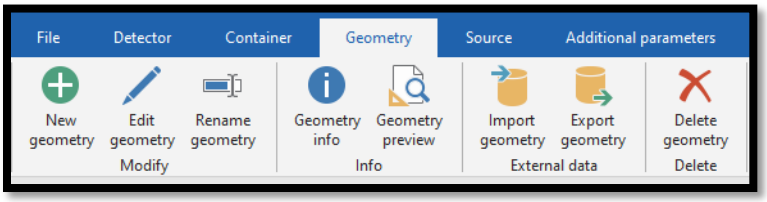

Figure 33. Geometry Ribbon Tab

In total, there are eight buttons:

- **New geometry** – to create a new geometry
- **Edit geometry** – to change the parameters of the already existing geometry
- **Rename geometry** – to rename a geometry
- **Geometry info** – to display the parameters of a geometry
- **Geometry preview** – to display a scaled preview image of a geometry
- **Import geometry** – to import a geometry from a file
- **Export geometry** – to export a geometry to a file
- **Delete geometry** – to delete a geometry

The alternative way is to use the pop-up menu with the same options, which you can open by right-clicking the list of geometries.

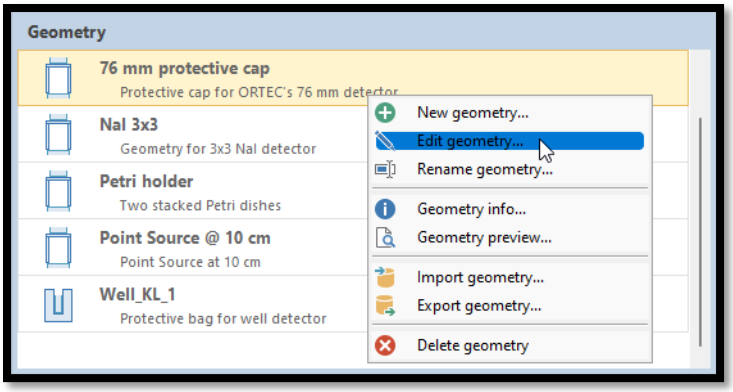

Figure 34. Geometry Pop-up Menu

First, you will have to enter the geometry name and to choose whether the geometry refers to a Well detector or Marinelli container, or not. In case you mark one of these two options, you will not be offered the opportunity to enter the data for the holder but will be able to specify the additional absorbing layers.

The next figure shows the geometry data entry window, with the preview image on the right-hand side and the dimension line indicating the parameter being edited (holder outer radius).

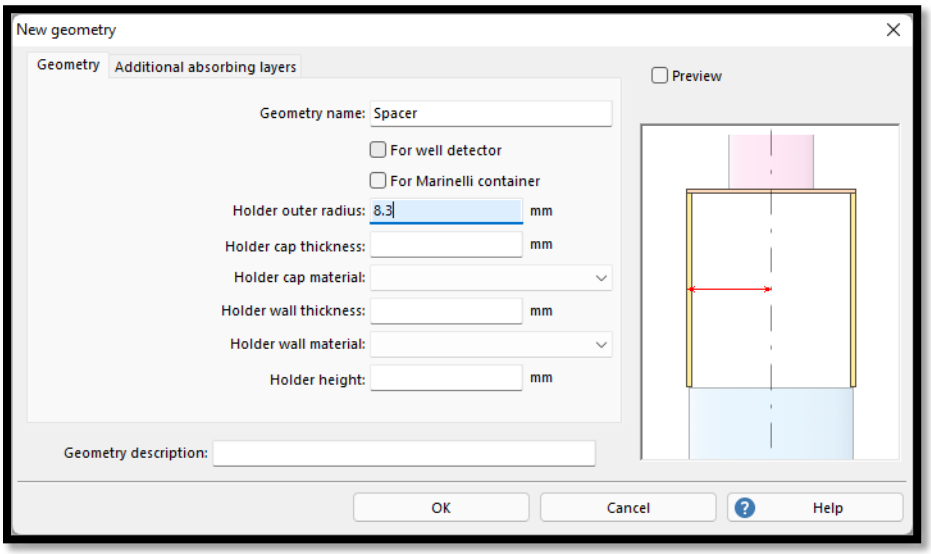

Figure 35. Geometry Data Entry

Additional absorbing layers (between the detector and the source) could be, for instance, thin protective plastic foils. You can enter up to five additional absorbing layers. For each of them you can define its top and side thickness and material separately.

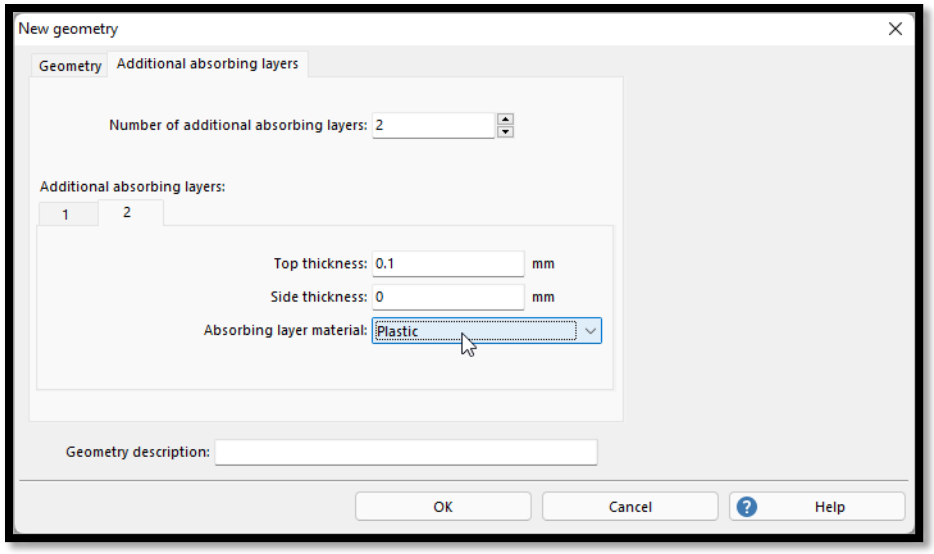

Figure 36. Additional Absorbing Layers

Above the illustration you can find a "**Preview**" check box. You can use it to see the scaled preview, instead of the generic illustration. The image is proportional, which is useful for detecting any obvious mistakes in the parameters, which would otherwise be hard to detect.

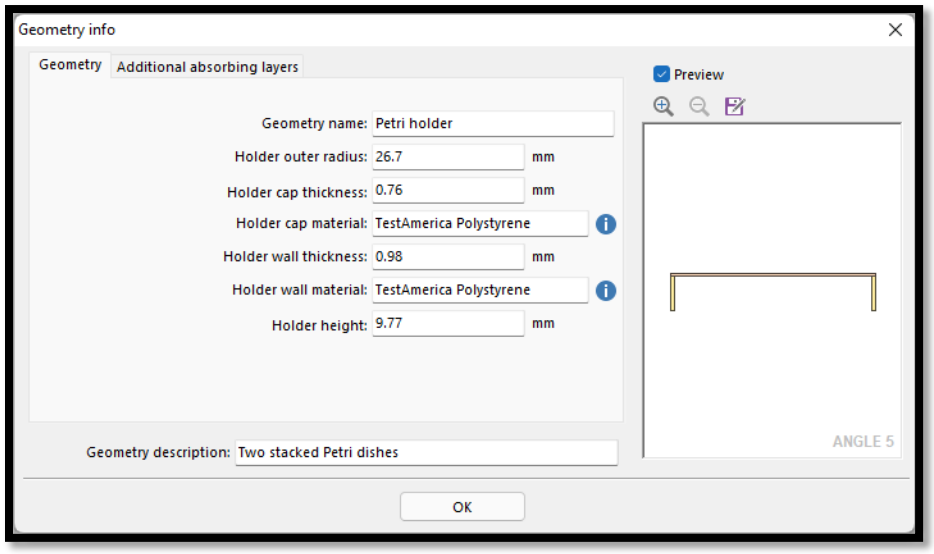

Figure 37. Geometry Preview

You can zoom-in and zoom-out the preview image, pan it and export it to various raster and vector graphics formats (read more in "**Data entry**" section).

To be able to see the preview image, all dimensions must be entered. Otherwise, no preview can be generated.

THIS PAGE INTENTIONALLY LEFT BLANK.

12. SOURCE

The radioactive source is defined by its height, radius, and material. The height and radius can be changed by simply by clicking the appropriate option in the **Source** group in the main ANGLE window and entering the new value.

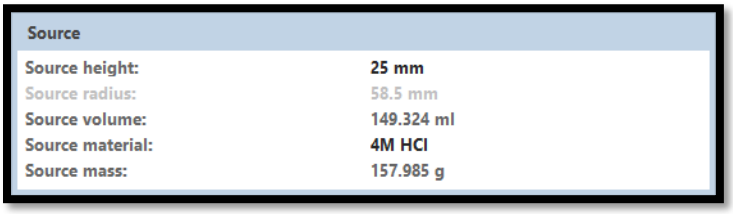

Figure 38. Radioactive Source Parameters

Source height can be equal to zero ("disk sources"). Also, both source height and radius can be equal to zero, in case of "point sources"; real sources, however, always have some small, non-zero dimensions.

When a container is selected, the source radius parameter automatically sets to the container's inner radius. This value can be changed if the source radius is smaller than the container inner radius (e.g. pill sources).

If the container type is Marinelli, it is not possible to alter the source radius, and it will always be the same as the container inner radius.

The volume and the mass of the source are automatically calculated from the parameters and displayed in the "Source" box. This is valuable information when checking whether the source parameters are correctly set.

Source material (as well as source height and radius) can be changed using buttons on the "**Source**" tab on the ribbon. You can choose one of the available materials or specify a new one.

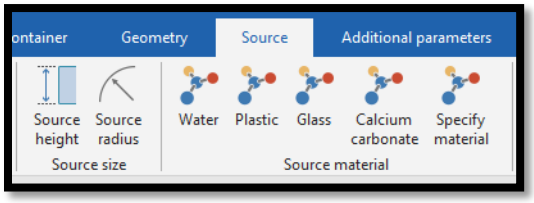

Figure 39. "Source" Ribbon Tab

Another, more flexible way, to select the source material is by using the pop-up menu, which you can open by clicking the "**Source material**" label.

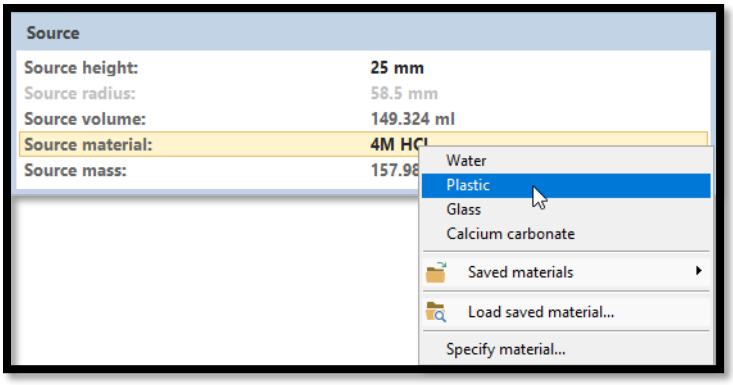

Figure 40. Choosing the Source Material

The source material pop-up menu contains two additional options. One is "Load saved material..." which opens a dialog to find a material file to load. The other one named "Saved materials" opens a sub-menu with the list of all saved materials, from which you can select any previously saved one with just one click.

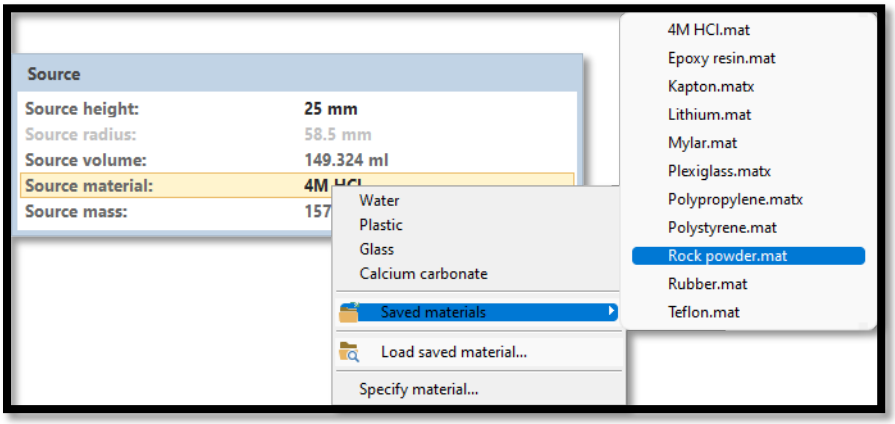

Figure 41. Choosing the Source Material from the List of Saved Materials

"Saved material" sub-menu is automatically populated with all the saved material files from the default material folder.

For more details on custom materials see the **"Custom Materials"** section.

13. REFERENCE EFFICIENCY CURVE

The key to efficiency calculations in ANGLE is the **reference efficiency curve** (REC). In order to calculate the detection efficiency for a given counting arrangement, some experimental measurements must be performed. These measurements are used as *reference* ones for future calculations.

The complete counting arrangement for the reference measurements must be defined as a part of the reference efficiency curve data, including detector, source, container, and geometry used.

Obtaining reliable reference efficiency curve is crucial for successful ANGLE utilization: all ANGLE results for a given detector will be relative to REC with an error propagation factor = 1; that is to say 100% of the uncertainty in the REC is added to the uncertainty budget of the calculated efficiencies.

Investing time and care in determining a reliable REC will always pay off!

You can define the reference efficiency curve by using the button "**Edit curve**" on the "**Additional parameters**" tab on the ribbon, or you can turn it off using the "**No curve**" button.

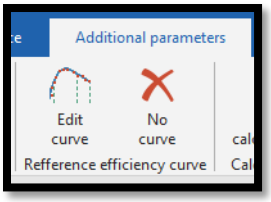

Figure 42. Reference Efficiency Curve Buttons

If the reference efficiency curve is not specified, efficiencies will not (cannot) be calculated! Only effective solid angles will be calculated in this case.

Another, more flexible way, to work with reference efficiency curves is by using the pop-up menu, which you can open by clicking the "**Reference efficiency curve**" label in the **Additional parameters** group of the main window.

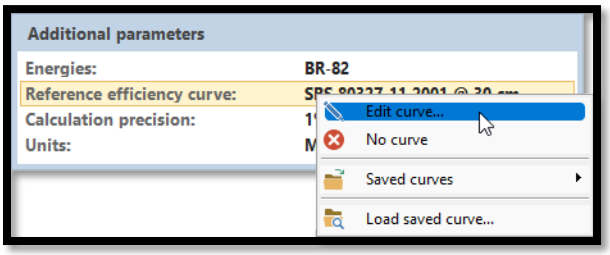

Figure 43. Reference Efficiency Curve Pop-up Menu

You can use the first option from the pop-up menu ("**Edit curve...**") to specify a new curve, or to change an existing one. The second option ("**No curve**") turns off the reference curve from subsequent calculations.

The reference efficiency curve pop-up menu contains two additional options. One is "Load saved curve..." which opens a dialog to select a reference efficiency curve file to load. The other one named "Saved curves" opens a sub-menu with a list of all the saved reference efficiency curves, from which you can select any previously saved one with just one click.

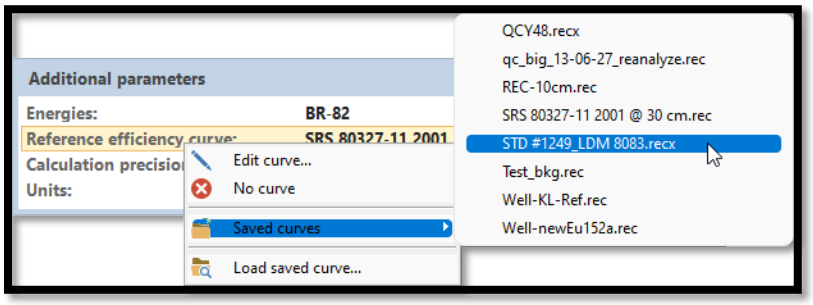

Figure 44. Choosing the Reference Efficiency Curve from the List of Saved Curves

The **"Saved curves"** sub-menu is automatically populated with all saved reference efficiency curve files from the default folder.

When defining a reference efficiency curve, several groups of parameters must be entered:

- Experimental points
- Interpolation regions
- Detector name
- Reference container data
- Reference geometry data
- Reference source data
- Reference curve name and description.

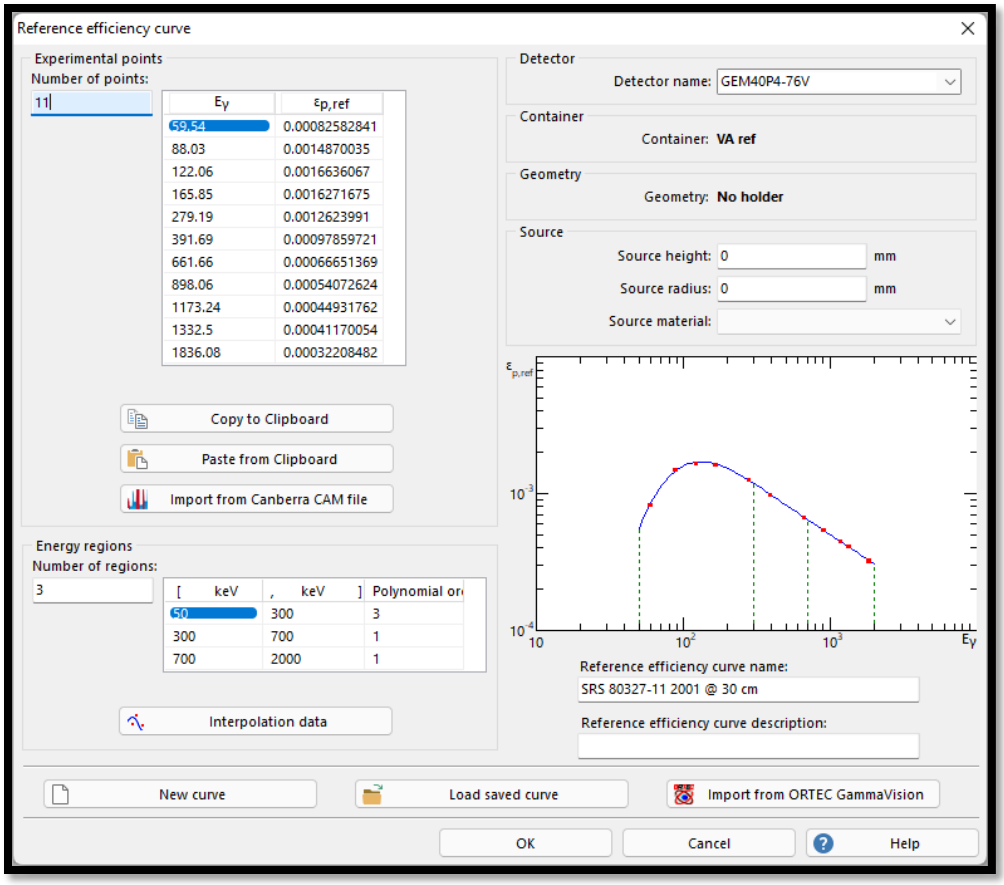

Figure 45. Reference Efficiency Curve Window

To create a new reference efficiency curve, click the "**New curve**" button. After this, the form will be cleared, and you will be able to enter the data for a new curve.

With the "**Load saved curve**" button, you can load the previously saved reference efficiency curve.

You can also load the curve from files with saved calculation parameters or calculation results. You just need to choose the appropriate file type in the file selection dialog.

13.1 ENTERING THE CURVE DATA

The most important data for each reference efficiency curve is the set of experimental points, i.e., the list of energy-efficiency pairs. You need to specify the number of points and the value pairs for each of them. The points will be automatically displayed on the log-log diagram in the right-hand part of the window.

Experimental points can be easily transferred from another application simply by copying the values there and pasting it using the "**Paste from Clipboard**" button.

Vice versa, you can copy the values to another application by clicking the "**Copy to Clipboard**" button.

In order to be able to calculate the efficiencies for any energy, not only those defined with the experimental points, ANGLE also needs to create a reference efficiency curve fitted through these experimental points. So as to create the best fit possible, you can divide the interpolation into intervals, each of which can be of different polynomial orders.

The intervals are defined by energy pairs (in *keV*) and polynomial order for that interval. These intervals are represented on the diagram with dashed green lines.

When interpolating the reference efficiency curve, ANGLE includes the closest points from the neighboring intervals in order to create a smoother curve.

Polynomial orders can have values from 0 to 6. Value "1" represents a linear fit, "2" is a quadratic fit, etc. If you enter the value "0" for the polynomial order, no interpolation will be used –points will be connected with straight lines (in the log-log space).

Although ANGLE supports polynomial fitting up to an order of 6, it is recommendable to divide the energy region of interest into several segments and fit each of them with polynomials of a lower order (not more than an order of 3). In so doing, error propagation factors from the input parameters into the REC are reduced.

If you do not specify interpolation regions (i.e., if you enter "0" as the number of regions), interpolation will not be used. This way, you will define a "**discrete curve**" – you will be still able to run calculations, but efficiencies will be calculated only for the energies which exist in the experimental points. This approach has some advantages; in cases when all energies of interest for calculation have their counterparts in the experimental points, exact efficiency values will be used, instead of interpolated ones, leading to better accuracy (again, only for given energies).

Discrete REC is particularly suitable for scintillation detectors, where often only one or a few gamma-energies recorded in the spectrum are relevant.

Next, you need to select the detector which was used for reference efficiency curve measurements. This parameter is used as a control parameter, to prevent running calculations using some other detector (of course, REC and calculated efficiencies **must** be for the **same detector**!).

One REC per detector is enough, in principle. It is recommended to construct it by counting a number of calibrated point sources at a large distance from the detector (e.g., 20–30 cm), avoiding any true coincidences and matrix effects. Also, absolutely calibrated point sources are often certified to a better accuracy than voluminous ones.

It is generally more prudent to use **several single-nuclide sources**, than a single multi-nuclide source.

However, in order to additionally exploit the **ET error-compensation effect**, one might consider constructing **more RECs for the same detector**. For instance, the same point source(s) counted at large distance could also be counted on the detector top, yielding another REC. Calibrated cylindrical and Marinelli sources could produce additional RECs. During exploitation, choosing REC geometry similar to the actual sample geometry should eventually produce better (more accurate) results, due to a larger ET error-compensation effect.

The next step is to define the container and geometry which were used for reference measurements. It is possible to define a new container/geometry, or to choose one of already defined containers/geometries.

For Well detectors, reference geometry can make use of a source holder (e.g., for point sources). Nevertheless, reference calibration is best with source placed in the well, as that will also be the case with actual samples.

If you click on **Container** label, a pop-up menu will be displayed, with the following options:

- **Define** – enter new reference container “from scratch”
- **Edit** – change reference container parameters
- **Info** – information about the reference container
- **No container** – if no reference container was used for reference measurements
- **Select container** – to choose one of containers already defined in ANGLE

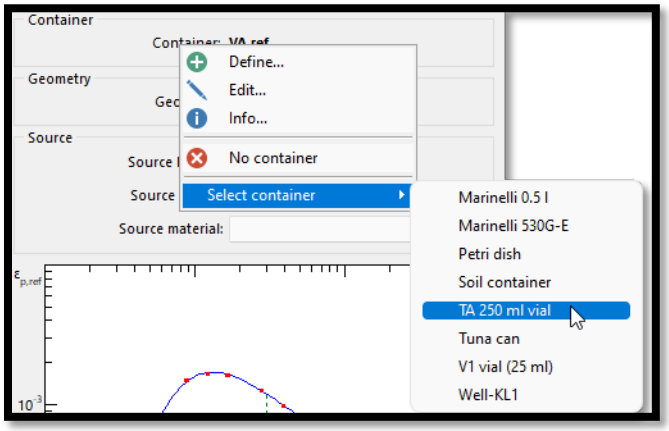

Figure 46. Reference Container Pop-up Menu

If you click on the **Geometry** label, a similar pop-up menu will be displayed, with the following options:

- **Define** – enter new reference geometry "from scratch"
- **Edit** – change reference geometry parameters
- **Info** – information about the reference geometry
- **No holder** – if no reference holder was used for reference measurements
- **Select geometry** – to choose one of geometries already defined in ANGLE

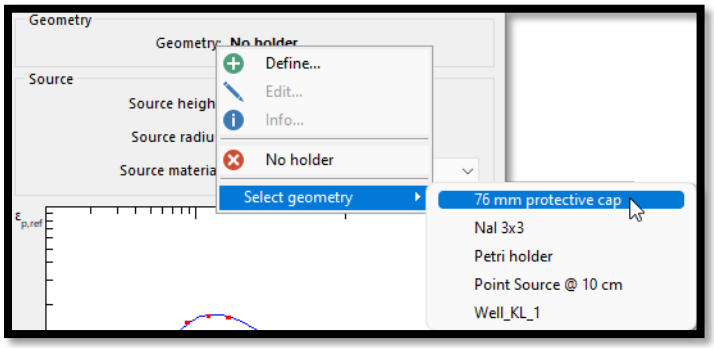

Figure 47. Reference Geometry Pop-up Menu

Finally, the radioactive source used for efficiency measurement has to be defined: its height, radius and material.

When you complete data entry and confirm it by clicking the "**OK**" button, you can choose whether the curve data will be saved to file or not.

We strongly suggest you save the curve for future reference. If you do not save it, you will still be able to use it for calculations, but only until you load another curve or select the **"No curve"** option. After that, all parameters will be lost, and you will have to re-enter them, if needed.

13.2 INTERPOLATION PARAMETERS

In ANGLE 5 it is possible to see the calculated polynomial coefficients and other interpolation parameters. To see this, click on the "Interpolation data" button in the "Energy regions" group.

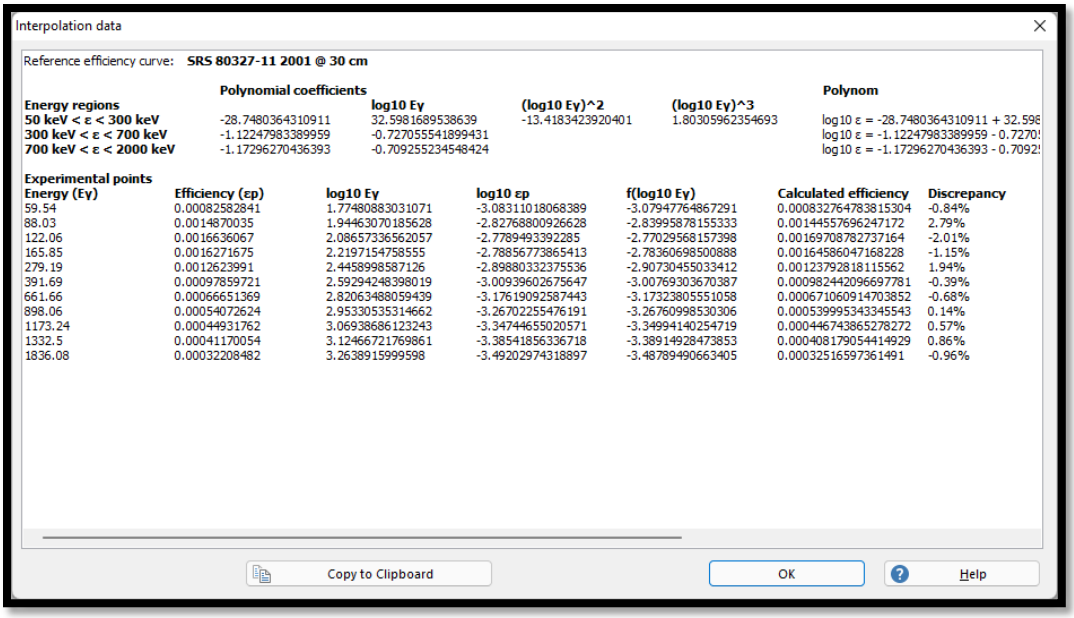

Figure 48. Interpolation Data Window

You can select and copy parts of the data to another application or click on "**Copy to Clipboard**" button and copy all at once.

13.3 IMPORTING A CURVE FROM ORTEC GAMMAVISION

A reference efficiency curve can be imported directly from ORTEC's **GammaVision** software by clicking the "**Import from ORTEC GammaVision**" button and choosing the GammaVision file containing curve data (".eft" extension).

ORTEC GammaVision files do not contain information about the detector, container, geometry or source. You have to specify them manually, after the import.

13.4 IMPORTING A CURVE FROM CANBERRA CAM FILES

The experimental points for a reference efficiency curve can also be imported from Canberra's **CAM files** by clicking the "**Import from Canberra CAM file**" button and choosing the Canberra CAM file containing experimental points data (".cnf" extension).

Canberra CAM files contain experimental points data, only. Other parameters must be specified manually.

Canberra software must be installed on your computer in order to be able to import CAM files into ANGLE.

THIS PAGE INTENTIONALLY LEFT BLANK.

14. CUSTOM MATERIALS

It is essential to specify all materials (for source, container, absorbing layers, detector elements, etc.) as accurately as possible. ANGLE offers a list of common materials for particular cases, but if none of them is adequate, you can specify the material manually or load it from a previously saved material file. To do this, choose the option "**Specify material...**" from the material drop-down list (figure **Error! Reference source not found.**), i.e. pop-up menu (figure **Error! Reference source not found.**). Any of these two options will open the material entry window. It is possible to define the material in three ways, each represented by buttons at the top of this window:

- As a mixture of elements
- As a compound
- As a mixture of compounds

When specifying the material as a mixture of elements, you have to define the number of elements, element symbols and mass shares in percentages.

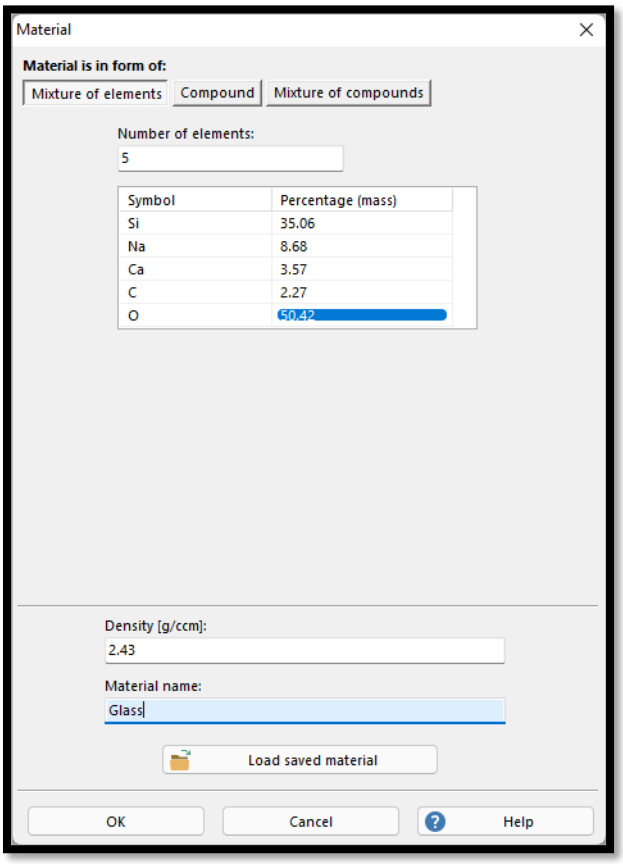

Figure 49. Specifying the Material as a Mixture of Elements

When entering the material as a compound, you have to enter the number of elements, element symbols and the number of atoms.

In ANGLE 5 you can enter the compound using the chemical formula – simply type it in the "**Chemical formula**" box and ANGLE will automatically break it down to symbols and atoms.

Formulae can be entered in condensed form. For example, **$Al_2(SO_4)_3$** can be entered in two ways: as **Al2S3O12** or **Al2(SO4)3**.

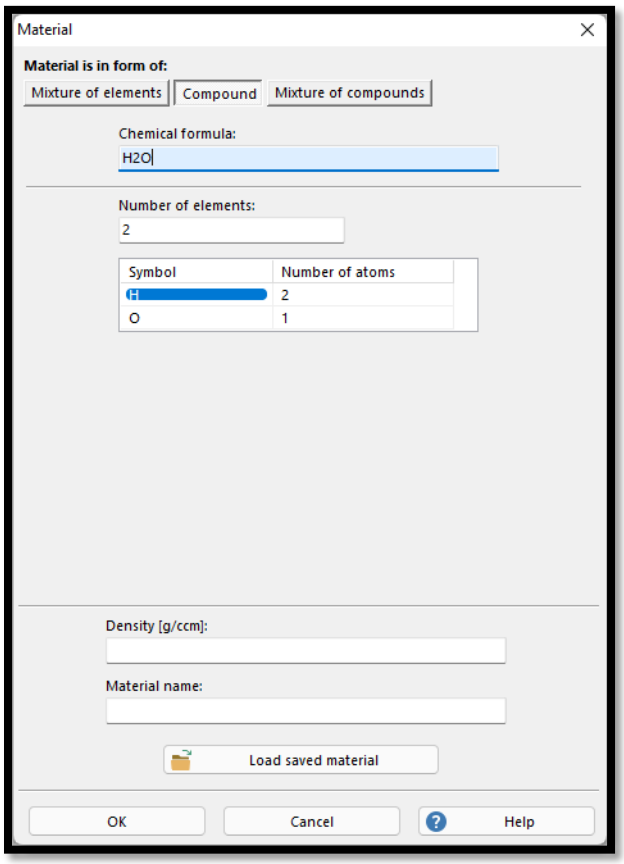

Figure 50. Specifying the Material as a Compound

Although ANGLE accepts both upper- and lower-case letters in formulae, you should pay attention to use the proper character case to avoid ambiguities. For example, "**caco3**" will be interpreted as **CaCo3** (one atom of calcium and three atoms of cobalt). Proper way to enter calcium carbonate is **CaCO3** (with uppercase letter "O").

ANGLE automatically breaks down the chemical formula to symbols and atoms and displays them in the table below. You should always use this table to check if the formula was entered correctly.

The third way to define a custom material is as a mixture of compounds. First, you need to enter the number of compounds. Then, you have to define each compound, as well as its mass share in the material, with each compound in a separate tab.

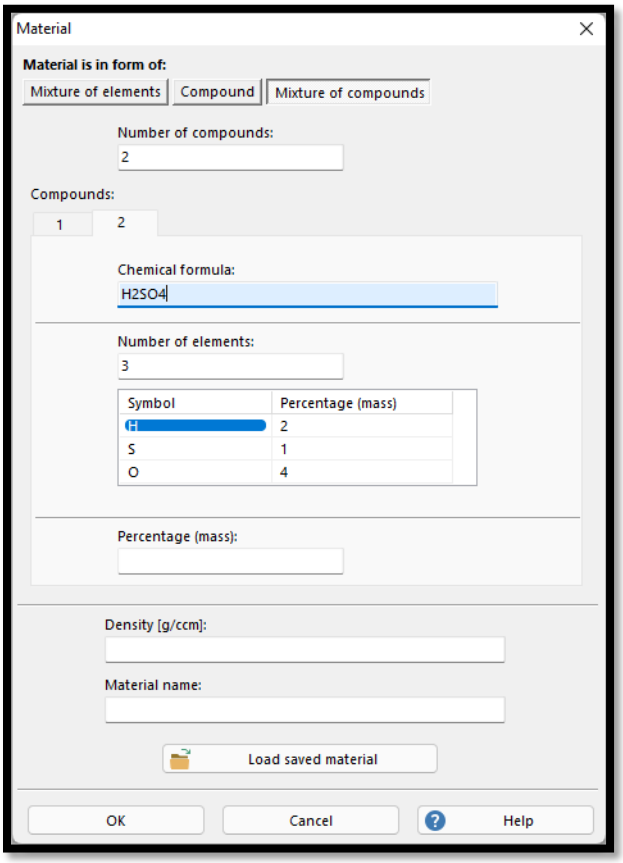

Figure 51. Specifying Mixture of Compounds

Finally, regardless of the way in which you define a material, you have to enter the material density and give it a name.

After you enter all material parameters click on the "**OK**" button to complete the procedure. At this point you will be asked if you would like to save the material to disk, for further use.

Knowing material composition as good as possible contributes to the accuracy of the calculated results. However, bear in mind that in work with regards to gamma-attenuation, **it is not necessary to know the exact material composition**, particularly not for materials in trace quantities.

However, **material density is crucial** for the proper accounting for gamma attenuation and should be known as accurately as possible; if not available otherwise, it is eventually a simple mass to volume ratio, both readily measurable.

One should be particularly vigilant when specifying the so called **"generic" materials** (e.g., rock, soil, sediment, ash, resin, plastic, glass, wood, concrete, etc.). Such generic names usually encompass a large number of materials with varying characteristics (including composition and density). Specifying the actual data, whenever possible, for the actual material is therefore highly advisable. Again, density has a substantial impact on the calculation result, so please **check for the actual density of the material**.

14.1 LOADING ALREADY SAVED MATERIAL

From the material entry dialog box, you can load any previously saved material by clicking on the **"Load Saved Material"** button and choosing a material file.

15. ENERGY SETS

To be able to perform calculations, you must specify a set of gamma-energies of interest (in *keV*). The set of energies represent the chosen gamma-energies for which ANGLE will calculate effective solid angles and full-energy peak efficiencies, which is the ultimate goal of the software.

From the calculated full-energy peak efficiencies, the concentrations/activities of radionuclides present in the sample are straightforwardly derived.

An energy set can be defined using the button "**Edit energy set**" on the "**Additional parameters**" tab on the ribbon.

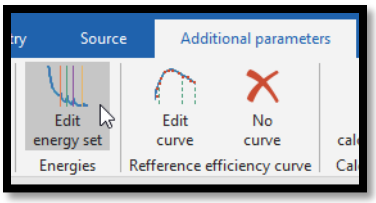

Figure 52. "Edit Energy Set" Button

Another, more flexible way, to define the energy set is using the pop-up menu, which you can open by clicking the "**Energies**" label.

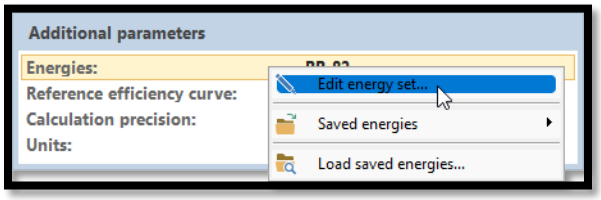

Figure 53. Energies Pop-up Menu

The energies pop-up menu contains two additional options. One is "**Load saved energies...**" which opens a dialog to find an energies file to load. The other one named "**Saved energies**" opens a sub-menu with the list of all the saved energies, from which you can select any previously saved one with just one click.

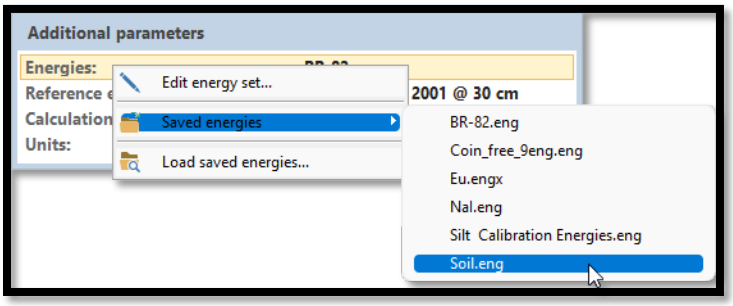

Figure 54. Choosing Energies From the List of Saved Energies

The "Saved energies" sub-menu is automatically populated with all saved energy files from the default energies folder.

By clicking the "**Edit energy set**" button or the pop-up menu option, the energy set dialog will be shown.

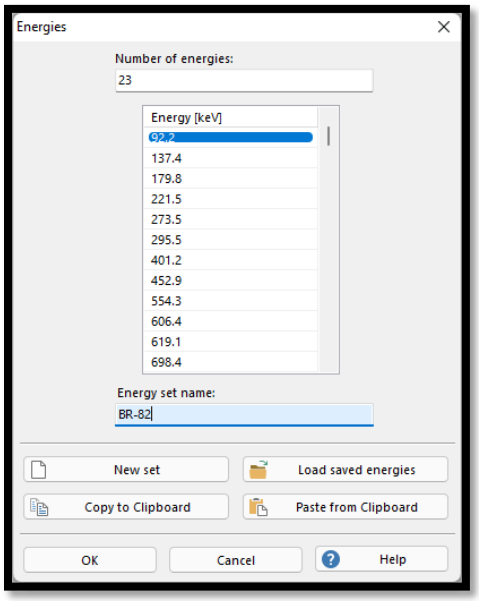

Figure 55. Defining the Energy Set

The dialog will display current energy set by default. From here you can change the set, enter a completely new set, or load a previously saved one from a disk.

To enter a new set of energies, just click on a "**New set**" button and specify the number of energies in the set. Then, populate the table with energy values (in *keV*). Finally, give a name to the energy set.

The whole energy set can be copied to or pasted from the Clipboard using the "**Copy to Clipboard**" and "**Paste from Clipboard**" buttons, respectively.

After clicking the "**OK**" button you will be prompted if you would like to save the energy to a file for future use.

15.1 LOADING AN ALREADY SAVED ENERGY SET

You can load a previously saved energy set by clicking on the "**Load saved energies**" button and choosing an energy file.

You can also load energies from files with saved calculation parameters or calculation results. You just need to choose the appropriate file type in the file selection dialog.

16. CALCULATION PRECISION

ANGLE calculations involve extensive Monte Carlo computation, based on the statistical simulation of the actual emission, attenuation and detection of photons in the counting process. Precision of these calculations is defined/set by the user, specifying the "target precision" (in percent). Higher/better precision (lower percentage) leads to longer calculations times. For a given precision, these times normally vary depending on the counting arrangement.

Calculations will proceed until the specified target precision is met for all of the specified energies.

ANGLE allows for the target calculation precision values between 0.1 and 5%. The selected calculation precision is displayed in the "**Additional parameters**" group.

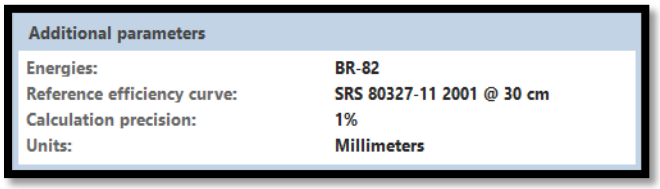

Figure 56. Additional Parameters Group

To change calculation precision, click the "**Calculation precision**" option in the "**Additional parameters**" group, or choose the ribbon tab "**Additional parameters**" and then click the button "**Change calculation precision**". In the calculation precision dialog simply enter the desired precision and click the "**OK**" button.

Higher (better) calculation precision (lower precision percentage) implies longer calculation times. However, new generations of computer processors allow for ever faster calculations. It is thus advisable not to "spare" on calculation precision if the corresponding calculation times are of no practical concern.

THIS PAGE INTENTIONALLY LEFT BLANK.

17. CALCULATIONS

Once you define all the calculation input parameters, you will be able to run efficiency calculations. To define these parameters, you need to:

- Select an appropriate detector, container, and geometry from the lists
- Define the radioactive source height and material (also its width, if it is different than the container inner radius)
- Choose the set of energies of interest for calculation
- Select the reference efficiency curve, if you want to calculate efficiencies (otherwise, only effective solid angles will be calculated)
- Choose the calculation precision

With all these parameters set, you are ready to run calculations, or to save these calculation parameters and run them some other time, or even on some other computer.

To perform calculations from the currently selected parameters, simply click the button "**From current parameters**" on the "**Calculations**" ribbon tab.

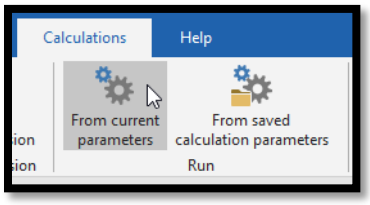

Figure 57. Calculation From Current Parameters

Before calculation starts, ANGLE checks all input values for possible incompatibilities. If there are one or more incompatibilities in the input parameters, such as the container not compatible with the detector (for example, if you try to use a well detector with a Marinelli container), you will get the error message and the calculations will not be performed.

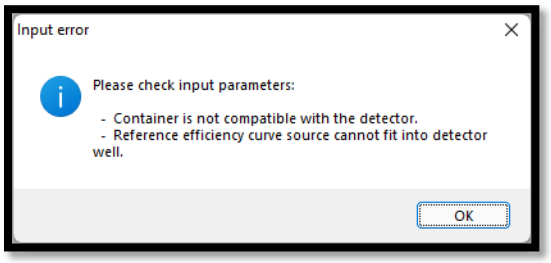

Figure 58. Error in Input Parameters

If all input parameters are correct, ANGLE will ask for the name of the file where the output results will be saved, and the calculations begins. While calculating, ANGLE displays information about the calculation, as shown in the next figure.

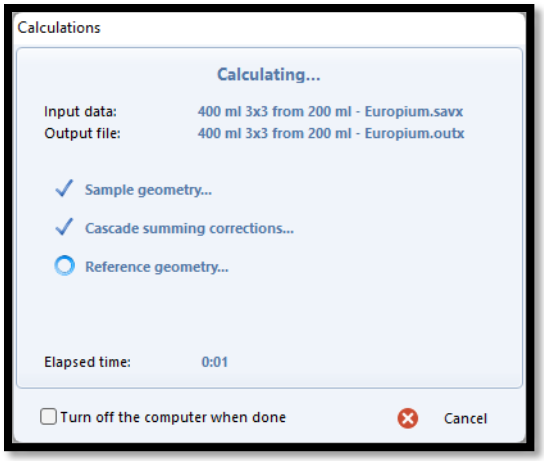

Figure 59. Calculation Information Box

The first label shows the source of the input parameters – the name of the parameter file or "Selected calculation parameters" in cases when running calculations from current parameters (more about the parameter files is in "**Saving input parameters**"). The second label shows the name of the output file.

Calculations take place in three phases:

- **sample geometry** calculations
- **cascade summing corrections** calculations
- **reference geometry** calculations (only in case a reference efficiency curve is selected)

Usually, calculation times are very short. Sometimes, depending on the calculation precision set and the counting arrangement used in calculations, calculations can take longer than a few seconds. In those cases, ANGLE will display the histogram with currently achieved precisions for each of the selected energies. The bars for energies for which the specified precision level was reached are displayed in green, as shown in the following figure.

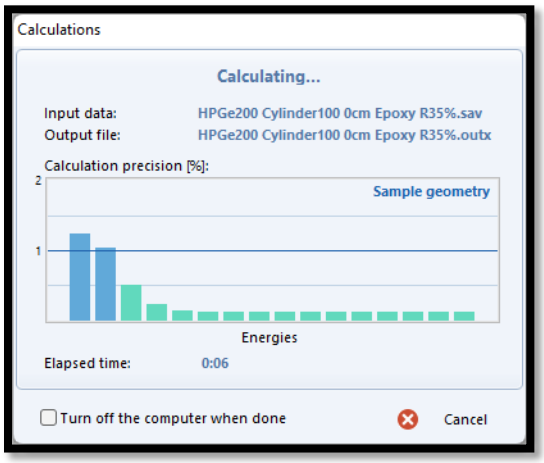

Figure 60. Histogram with Achieved Calculation Precisions

Calculations can be canceled anytime by clicking the "**Cancel**" button

If you check the option "**Turn off the computer when done**", the computer will be shut down automatically when calculations finish. This is useful for time consuming calculations (e.g., long batch jobs), where computers are left unattended to finish calculations. Once all calculations are finished, the shutdown dialog will be displayed:

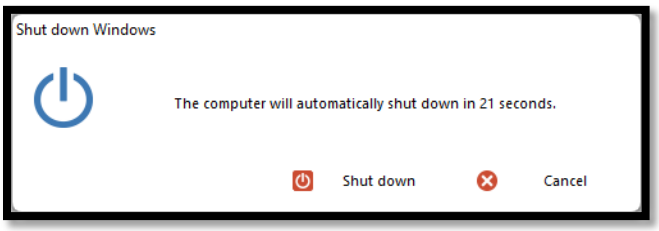

Figure 61. Automatic Shutdown Dialog

The shut down dialog will start a 30-second countdown, after which the shut down procedure will be initiated. During this period, it is possible to cancel the shut down, or even force it before the timer reaches zero.

On Windows Vista and newer operating systems, ANGLE can display the calculation progress on the Windows Taskbar. This is useful in case of lengthy calculations (e.g., running many calculations at once), so you can monitor the progress of calculations while working in other applications, even if the ANGLE window is not visible (Figure 18). To see how to enable or disable this functionality, see "**Configuration**" section.

17.1 CALCULATION RESULTS

After the calculations are finished, a window with the calculation results will be displayed automatically.

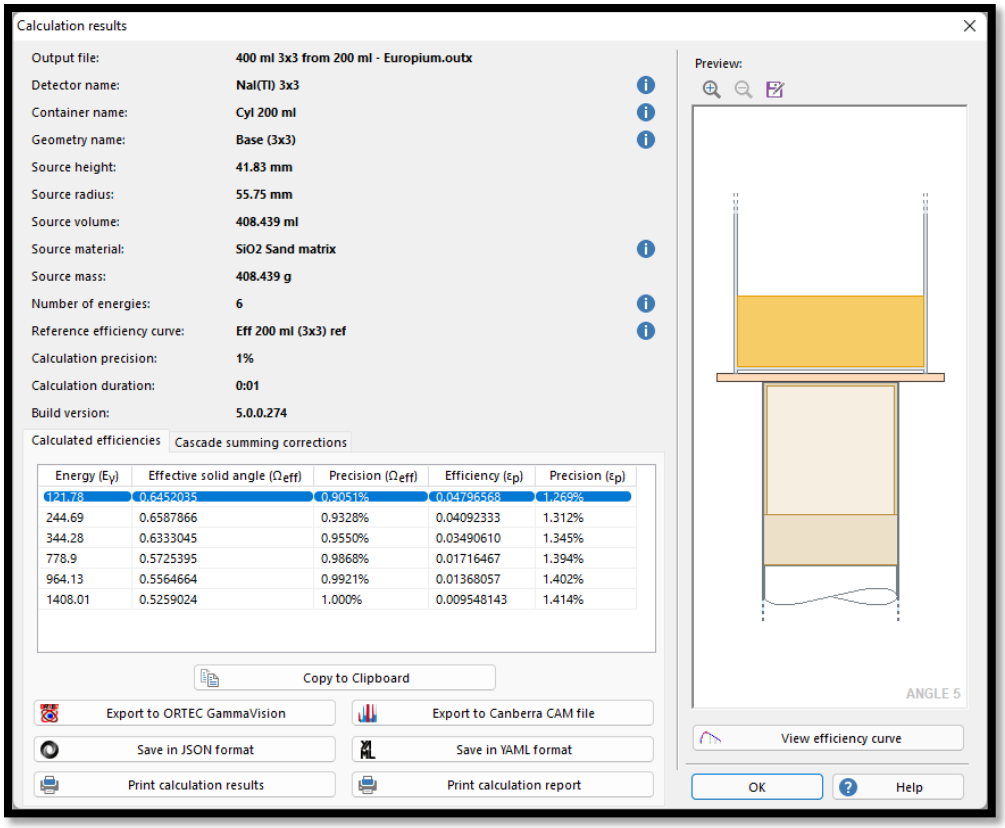

Figure 62. Calculation Results Window

The calculation results window displays all input parameters used for calculation: detector, container, reference efficiency curve, etc. To see the details for each of them, simply click on the name of the parameter, or the "info" button on the right-hand side of it.

The input parameters containing detailed information can be recognized by the "info" button at the right-hand side. Also, the cursor changes its shape to a pointing hand when moving over these parameters (Figure 62).

The scaled preview of the whole counting arrangement is displayed in the right-hand part of the calculation result window. As with other previews, you can also zoom-in and zoom-out the preview image, pan it and export it to various raster and vector graphics formats (read more in the "**Data entry**" section).

17.2 CALCULATED EFFICIENCIES

Calculation results are shown in a table under the "**Calculated efficiencies**" tab: values of the effective solid angle ($\overline{\Omega}_{eff}$) and efficiency (ε_p) are shown for each energy from within the given energy set, as well as the estimated calculation precisions.

The ε_p values will be calculated only if the reference efficiency curve is defined. Otherwise, only $\overline{\Omega}_{eff}$ values are calculated.

Calculated efficiencies can be copied to the Clipboard by clicking the "**Copy to Clipboard**" button and then pasted to other programs, for example to spreadsheet or word processing software.

17.3 CASCADE SUMMING CORRECTIONS

Cascade summing corrections (CSC) for all nuclides are displayed under the "**Cascade summing corrections**" tab, as shown in the following figure:

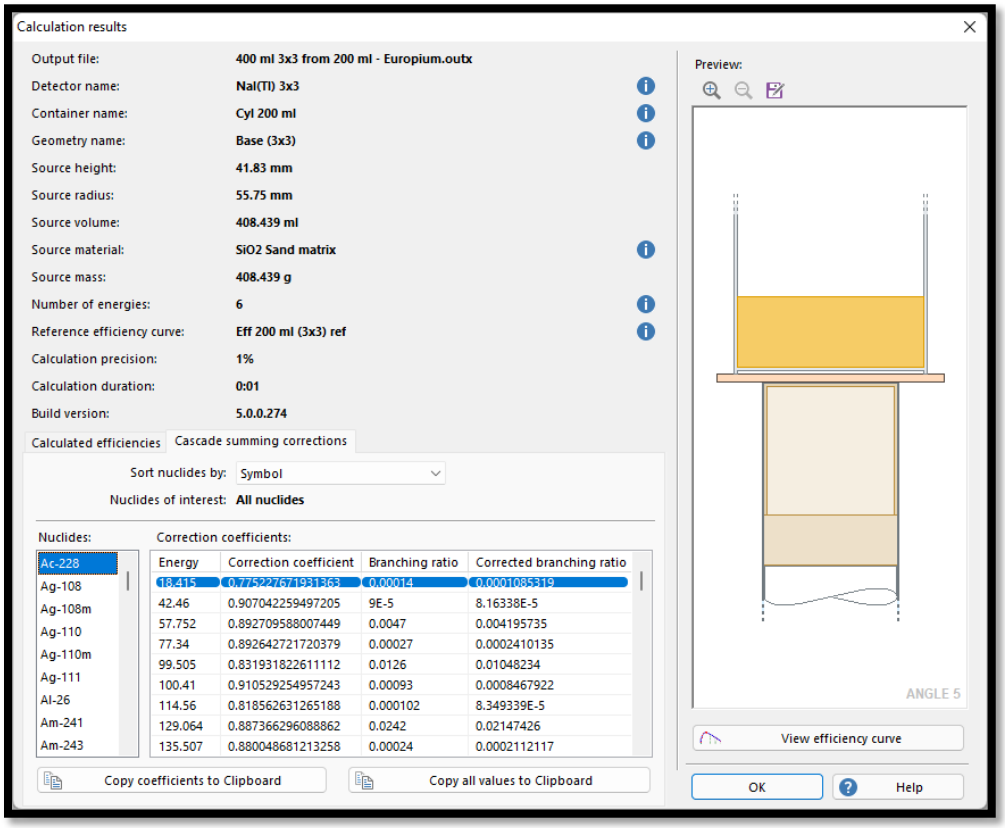

Figure 63. Cascade Summing Corrections

In order to easily locate nuclides of interest, the results can be sorted using the "**Sort nuclides by**" drop-down. Nuclides can be sorted by:

- **symbol**
- **atomic mass**
- **energy**

Depending on which of these three options is selected, the list on the left-hand side of this tab will contain nuclides sorted by name or by atomic mass, or list of energies. Upon clicking the values in this list, the table right to it will display the appropriate values:

- **nuclide** or **energy**
- **correction coefficient**
- **branching ratio** (emission probability)
- **corrected branching ratio**

Calculated cascade summing corrections can be copied to the Clipboard and pasted to other programs by clicking one of the following two buttons:

- "**Copy coefficient to Clipboard**" button will copy the values for the selected nuclide/energy.
- "**Copy all values to Clipboard**" button will copy the values for all nuclides.

Since the list of nuclides supported by ANGLE is rather extensive, it is possible to select just a subset of these nuclides that interest you. To do that, use one of the options from the pop-up menu, which you can open by clicking the "**Nuclides of interest**" label.

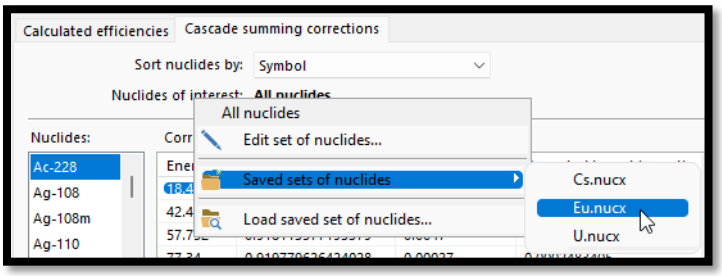

Figure 64. Choosing the Nuclides of Interest

The first option from the pop-up menu ("**All nuclides**") will show the data for all nuclides. To select the previously saved set of nuclides, you can simply choose one using the "**Saved sets of nuclides**", or locate a file with the nuclide set using the "**Load saved set of nuclides...**" option. The second option from the pop-up menu ("**Edit set of nuclides...**") lets you specify a new set of nuclides of interest.

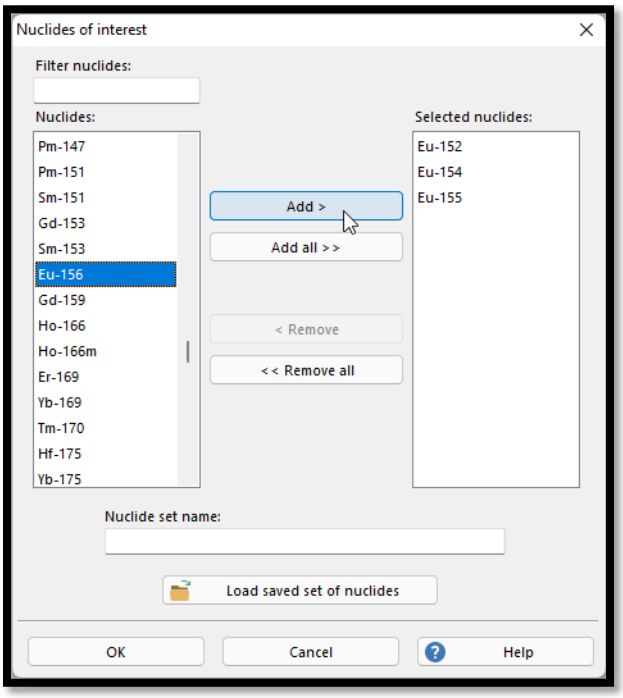

Figure 65. Specifying Set of Nuclides of Interest

You can add the nuclides to the new set one by one by selecting it on the left-hand list and clicking the "**Add >**" button, or simply by double-clicking it. You can filter the list of nuclides using the "**Filter nuclides**" field. For example, if you type "Na" in this field, you will get two nuclides: *Na-22* and *Na-24*, which you can both add to your set by clicking the "**Add all >>**" button. To remove the selected nuclides, you can use the "**< Remove**" and "**<< Remove all**" buttons.

When you finish defining the nuclides of interest, you just need to give your set a name and click the "**OK**" button. You will be prompted if you would like to save the set of nuclides to a file for future use.

The files with the calculation results (".outx" extension) contain the full list of nuclides, regardless of the selection of the selected set of nuclides. Therefore, you can switch between the different nuclide groups and see the cascade summing corrections without having to re-run the calculations.

17.4 RE-OPENING THE CALCULATION RESULTS

Calculation results can be opened and reviewed anytime later by re-opening the calculation result files. To do this, choose the "**View calculation results**" option from the "**Calculation**" ribbon tab and select the calculation results files to display.

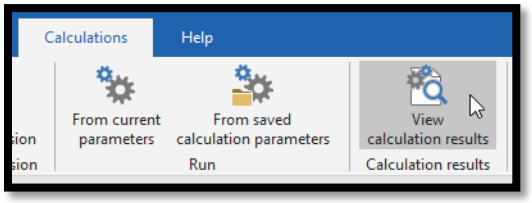

Figure 66. Viewing Calculation Results

It is possible to select more than one calculation results file:

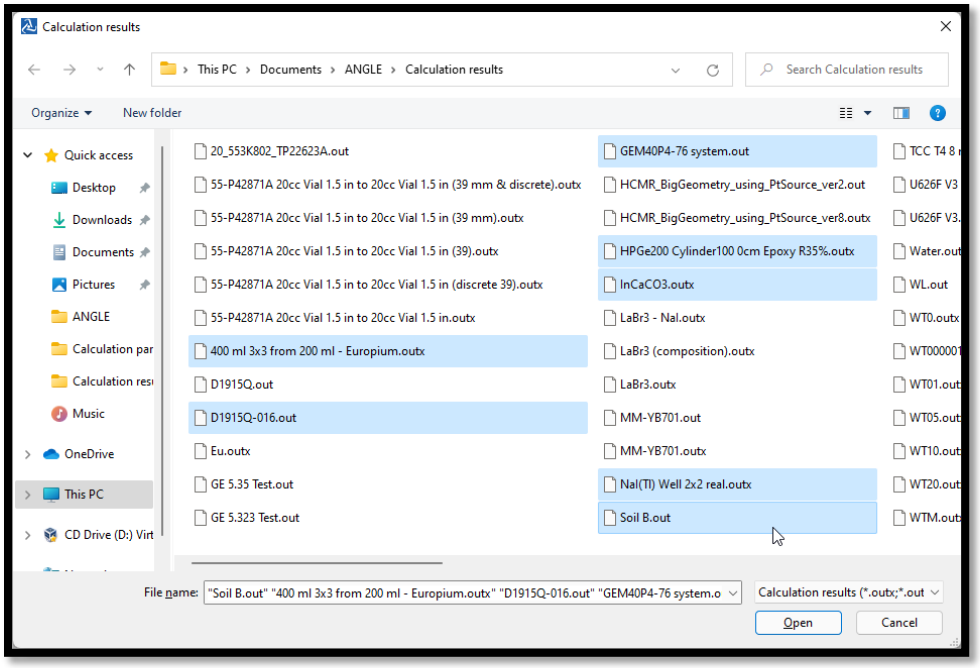

Figure 67. Selecting Multiple Calculation Results Files

To select multiple files, use any of the following standard Windows procedures (or their combination):

- By clicking a file name while holding the keyboard **Ctrl** key you can select/deselect one or more files.
- By clicking one file name and then clicking on another file name while holding down the **Shift** key, all files between those two will be selected.
- By pressing the **Ctrl+A** key combination you can select all files in the folder.

If you select more than one file to display, the calculation results window will contain a list of files in the left-hand part of the window. By clicking a name of a file, the results from that file will be displayed in the right-hand part of the window. This option is useful when comparing the results of calculations or when transferring the results to another application.

When opening the calculation results from previous versions of ANGLE, the window with the calculation results will not contain the precision estimation, or cascade summing corrections, since they are introduced with ANGLE 5.

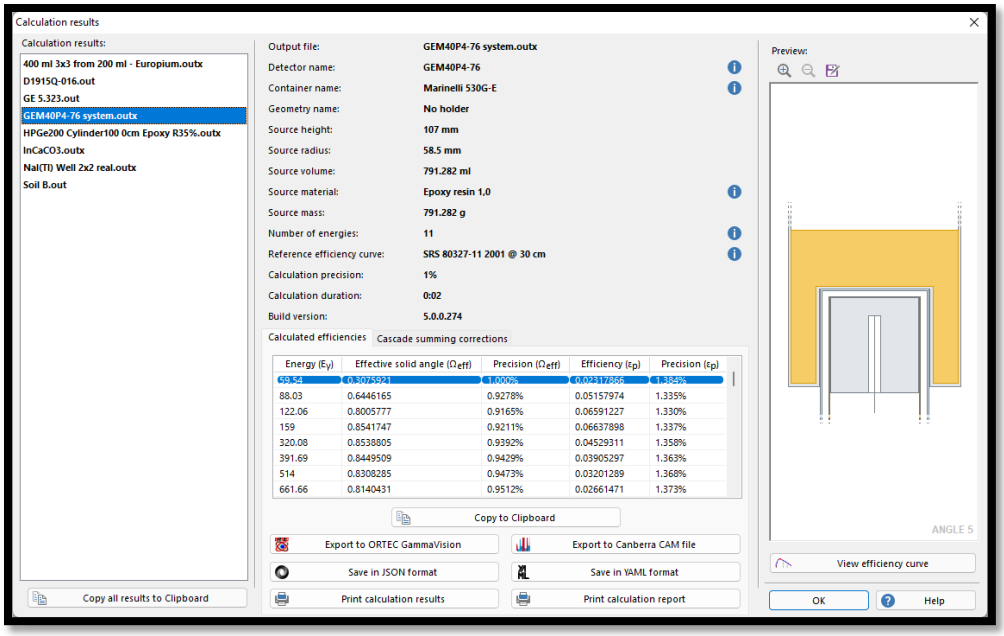

Figure 68. Multiple Calculation Results Window

To copy the results from all files at once, click the button "**Copy all results to Clipboard**", located under the list of files.

17.5 CALCULATION REPORTS

To print calculation results simply click the "**Print calculation results**" button. The resulting one-page document will contain the results, together with the summary of the input parameter data, counting arrangement schematics, and calculated efficiency curve (if efficiencies were calculated).

If you want to print a detailed report, you can do it by clicking on the "**Print calculation report**" button. The report will contain the results, as well as all the input parameter data used in calculations – thus **making the results traceable to the input values**.

Traceability of results down to input parameters is important for e.g., validation and/or accreditation purposes.

17.6 CALCULATED EFFICIENCY CURVE

ANGLE 5 introduces another new feature – now you can see and export the graph of the calculated efficiency curve. To see it, click on the "View efficiency curve" button, located just below the preview image in the calculation results window (figures **Error! Reference source not found.** and **Error! Reference source not found.**). The efficiency curve graph window is shown in the next figure.

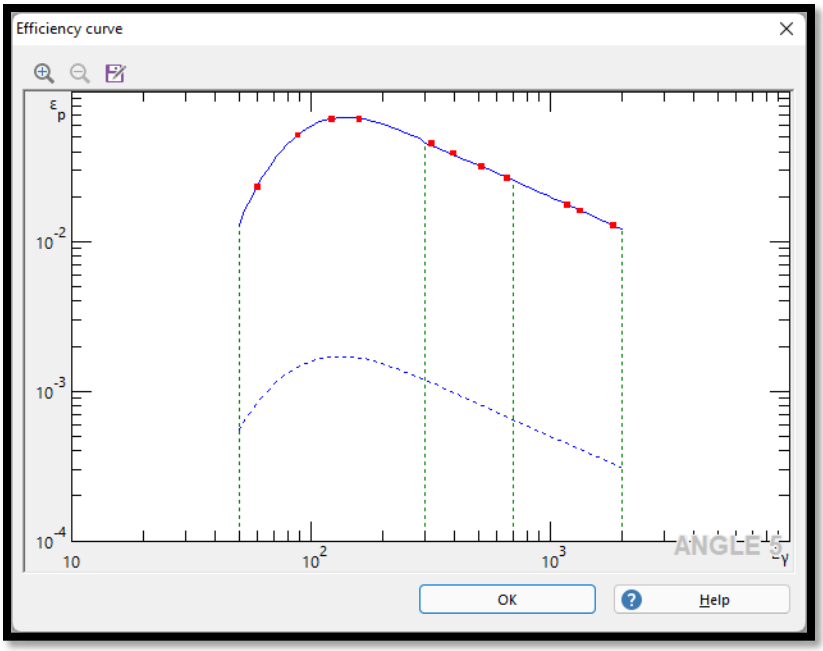

Figure 69. Efficiency Curve Graph

The graph shows both the calculated efficiencies for selected energies (red square markers) and the fitted efficiency curve (solid blue line). The *reference efficiency curve* is shown as well (dashed blue line). ANGLE uses the same intervals and polynomial orders for both curves.

To be able to calculate efficiencies, ANGLE needs you to specify the reference efficiency curve.

As with other previews, you can also zoom-in and zoom-out the preview image, pan it and export it to various raster and vector graphics formats (read more in "**Data entry**" section).

17.7 EXPORTING TO JSON AND YAML FORMAT

The calculation results are saved in XML format by default (with the ".outx" extension). The calculations can also be saved to widely used JSON and YAML formats by clicking the "**Save in JSON format**" and "**Save in YAML format**" buttons, respectively.

17.8 EXPORTING TO ORTEC GAMMAVISION

The calculation results can be exported to **ORTEC GammaVission** format, simply by clicking on "**Export to ORTEC GammaVision**" button (Figure 62 and Figure 68).

Export to ORTEC GammaVision will be possible only when efficiencies have been calculated, i.e., when a reference efficiency curve is defined. Otherwise, the "**Export to ORTEC GammaVision**" button will be disabled.

17.9 EXPORTING TO CANBERRA CAM FILES

Calculation results can also be exported to the Canberra **CAM file** format, simply by clicking on "**Export to Canberra CAM file**" button (Figure 62 and Figure 68).

Export to Canberra CAM file will be possible only when efficiencies have been calculated, i.e., when a reference efficiency curve is defined. Otherwise, the "**Export to Canberra CAM file**" button will be disabled.

Canberra software must be installed on your computer in order to be able to export CAM files from ANGLE.

17.10 SAVING INPUT PARAMETERS

All calculation parameters can be saved to a file and be used for further calculations later. This is convenient, for instance:

- When calculations will not be performed immediately.
- For preparing calculations which will be performed on another computer.
- For preparing the inputs for multiple calculations at the same time (batch jobs).

To save calculation parameters to a file, select all calculation parameters in the same way as when running calculations and click the button "**Save calculation parameters**" from the ribbon tab "**File**", or by pressing the **Ctrl+S** key combination on the keyboard.

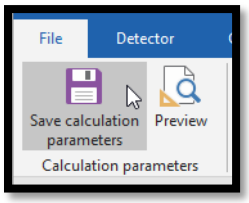

Figure 70. Saving Calculation Parameters

Before saving, ANGLE checks all input values for possible incompatibilities. If there is an incompatibility in the input parameters, such as an invalid detector-container combination (for example when using a well detector with a Marinelli container), the error message will be shown, and file will not be saved (Figure 58).

17.11 RUNNING CALCULATIONS FROM SAVED PARAMETER FILES

To perform calculations from one or more saved parameter files, click on "**From saved calculation parameters**" from the "**Calculations**" ribbon tab.

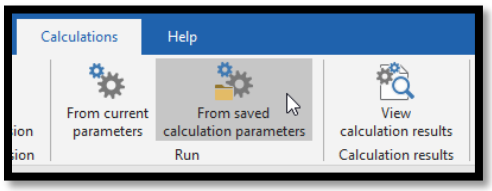

Figure 71. Starting Calculations From Saved Files

After choosing one or more previously saved calculation parameters files, the calculation begins. The output files will have the same name as the input files (except for the extension, which will be ".outx").

If you selected more than one file for calculations, the dialog box displaying calculation progress will additionally contain the information about the overall progress, the number of files being processed and the elapsed time for the overall process.

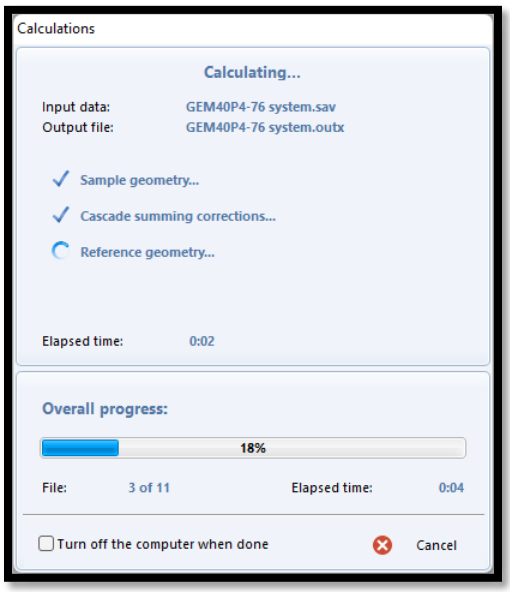

Figure 72. "Calculations" Information Box for Multiple Calculations

Output files will have the same names as the input ones. If output files with the same names exist, they will be overwritten without warning.

After the calculations are finished, the output results will be automatically displayed for all selected files, except in cases when an automatic computer shut down is requested.

17.12 RUNNING CALCULATIONS FROM CALCULATION RESULTS FILES

Since the calculation results files contain all input parameters, it is possible to run the calculations using them as input files. This can be convenient to re-run the calculations performed in older versions of ANGLE in order to get the coincidence summing corrections or precision estimations, or to convert the parameters to XML format from the legacy binary files (ANGLE 3 and earlier).

To perform calculations from one or more calculation result files, click on "**From saved calculation parameters**" from the "**Calculations**" ribbon tab (Figure 66) and select "**Calculation results**" file type.

When running calculations from files generated with previous versions of the ANGLE, the default precision of 1% will be used.

18. UPDATING ANGLE

ANGLE has a built-in automatic update function. In the configuration dialog box, you can choose how often you would like ANGLE to automatically check for updates (see "**Configuration**").

It is also possible to manually check for updates at any time. To do that, click the "**Check for updates**" button on the "**Help**" ribbon tab.

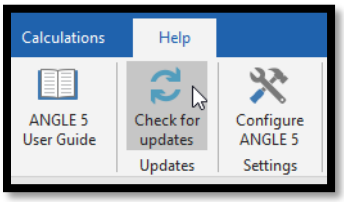

Figure 73. Update Button

To be able to check for updates and to download them, the computer must be connected to the internet.

The update dialog will contact the update server using your internet connection to check if there are updates available. If a new version of ANGLE is found, you will be offered the chance to install it.

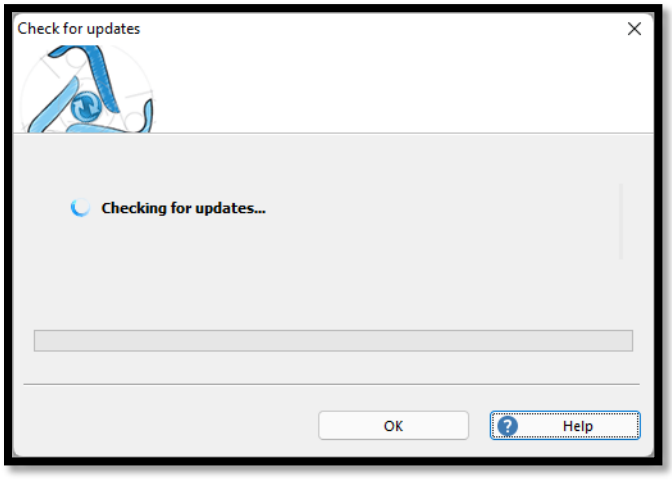

Figure 74. Update Dialog

Security software, such as antivirus or firewall may interfere and not allow ANGLE to update. If so, please contact your system administrator to resolve the issue.

THIS PAGE INTENTIONALLY LEFT BLANK.

19. ANGLE ON THE WEB

To see the most recent information about ANGLE, please visit our web page: **www.angle.me**. There you can find the latest news about ANGLE, explore its functionalities, see the frequently asked questions with answers, download the latest version of ANGLE, see the list of the most prominent users, pose a question to the developers, send a quotation request, etc.

The easiest way to access the ANGLE home page is using the "**ANGLE Home Page**" button on the "**Help**" button bar.

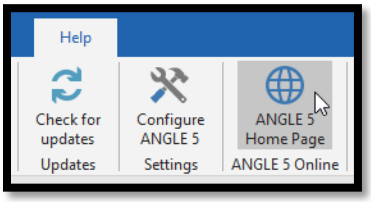

Figure 75. Button for Easy Access to ANGLE 5 Home Page

THIS PAGE INTENTIONALLY LEFT BLANK.

20. LITERATURE

[1] **ANGLE v2.1 – New version of the computer code for semiconductor detector gamma-efficiency calculations**, S. Jovanovic, A. Dlabac and N. Mihaljevic, *Nuclear Instruments and Methods in Physics Research Section A*, Volume 622, Issue 2, October 2010, Pages 385-391

[2] **Testing efficiency transfer codes for equivalence**, T. Vidmar, N. Çelik, N. Cornejo Díaz, A. Dlabac, I. O. B. Ewa, J. A. Carrazana González, M. Hult, S. Jovanović, M. C. Lépy, N. Mihaljević, O. Sima, F. Tzika, M. Jurado Vargas, T. Vasilopoulou and G. Vidmar, *Applied Radiation and Isotopes*, Volume 68, Issue 2, February 2010, Pages 355-359

[3] **Accounting for detector crystal edge rounding (bulletization) in gamma-efficiency calculations – theoretical elaboration and practical application in ANGLE software**, N. Mihaljević, A. Dlabač, and S. Jovanović, *Nuclear Technology and Radiation Protection*, Volume XXVII, No. 1, March 2012, Pages 1-12

[4] **Evaluation of ANGLE®, a code for calculating HPGe detector efficiencies**, V. M. Homan, Los Alamos National Laboratory, Report LA-UR--10-07191

[5] **Reliability of two calculation codes for efficiency calibrations of HPGe detectors**, K. Abbas, F. Simonelli, F. D'Alberti, M. Forte and M. F. Stroosnijder, *Applied Radiation and Isotopes*, Volume 56, Issue 5, May 2002, Pages 703-709

[6] **Experimental verification of gamma-efficiency calculations for scintillation detectors in ANGLE 4 software**, A. A. Thabet, A. D. Dlabac, S. I. Jovanovic, M. S. Badawi, N. N. Mihaljevic, A. M. El-Khatib, M. M. Gouda and M. I. Abbas, *Nuclear Technology and Radiation Protection*, Volume XXX, No. 1, March 2015, Pages 35-46

[7] **Well-type NaI(Tl) detector efficiency using analytical technique and ANGLE 4 software based on radioactive point sources located out the well cavity**, A. M. El-Khatib, M. S. Badawi, A. A. Thabet, S. I. Jovanovic, M. M. Gouda, M. M. Mohamed, A. D. Dlabac, M. Abd-Elzahere, N. N. Mihaljevic and M. I. Abbas, *Chinese Journal of Physics*, in press

[8] **Methods and software for predicting germanium detector absolute full-energy peak efficiencies**, K. R. Jackman and S. R. Biegalski, *Journal of Radioanalytical and Nuclear Chemistry*, Volume 279, Number 1/January, 2009, Pages 355-360

[9] **Evaluation of Efficiency Calibration Methods of Semiconductor Gamma Spectrometers**, J. Slivka, I. Bikit, M. Veskovic, M. Krmar, N. Todorovic, D. Mrdja and S. Forkapic, *Journal of Research in Physics*, Volume 31, Issue 1, February 2007, Pages 19-30

[10] **An investigation of HPGe gamma efficiency calibration software (ANGLE v.3) for applications in nuclear decommissioning**, S. J. Bell, S. M. Judge, P. H. Regan, *Applied Radiation and Isotopes*, Volume 70, Issue 12, December 2012, Pages 2737–2741

[11] **Modeling the impact of uncertainty in detector specification on efficiency values of a HPGe detector using ANGLE software**, M. Miller and M. Voutchkov, *Nuclear Technology and Radiation Protection*, Volume XXVIII, No. 2, June 2013, Pages 169-181

[12] **Calculation of the absolute peak efficiency of gamma-ray detectors for different counting geometries**, L. Moens, J. De Donder, Lin Xi-lei, F. De Corte, A. De Wispelaere, A. Simonits and J. Hoste, *Nuclear Instruments and Methods in Physics Research*, Volume 187, Issues 2-3, 15 August 1981, Pages 451-472

[13] **Calculation of the absolute peak efficiency of Ge and Ge(Li) detectors for different counting geometries**, L. Moens, F. De Corte, A. Simonits, Lin Xilei, A. De Wispelaere, J. De Donder and J. Hoste, *Journal of Radioanalytical and Nuclear Chemistry*, Volume 70, Issue 1-2, 1982, Pages 539-550

[14] **Calculation of the peak efficiency of high-purity germanium detectors**, L. Moens and J. Hoste, *The International Journal of Applied Radiation and Isotopes*, Volume 34, Issue 8, August 1983, Pages 1085-1095

[15] **The need for cylindrical germanium gamma ray detectors with accurately specified dimensions**, L. Moens and K. Debertin, *Nuclear Instruments and Methods in Physics Research Section A*, Volume 238, Issue 1, 15 July 1985, Pages 180-181

[16] **ANGLE: A PC-code for semiconductor detector efficiency calculations**, S. Jovanović, A. Dlabač, N. Mihaljević and P. Vukotić, *Journal of Radioanalytical and Nuclear Chemistry*, Volume 218, Number 1/April, 1997, Pages 13-20

[17] **On the applicability of the effective solid angle concept in activity determination of large cylindrical sources**, P. Vukotić, N. Mihaljević, S. Jovanović, S. Dapčević, and F. Boreli, *Journal of Radioanalytical and Nuclear Chemistry*, Volume 218, Number 1/April, 1997, Pages 21-26

[18] **"EXTSANGLE" – An extension of the efficiency conversion program "SOLANG" to sources with a diameter larger than that of the Ge-detector**, N. Mihaljević, S. Jovanović, F. De Corte, B. Smodiš, R. Jaćimović, G. Medin, A. De Wispelaere, P. Vukotić and P. Stegnar, *Journal of Radioanalytical and Nuclear Chemistry*, Volume 169, Number 1/March, 1993, Pages 209-218

[19] **Introduction of Marinelli effective solid angles for correcting the calibration of NaI(Tl) field gamma-ray spectrometry in TL/OSL dating**, F. De Corte, S. M. Hossain, S. Jovanović, A. Dlabač, A. De Wispelaere, D. Vandenberghe and P. Van den Haute, *Journal of*

Radioanalytical and Nuclear Chemistry, Volume 257, Number 3/September, 2003, Pages 551-555

[20] **Contribution of ^{210}Pb bremsstrahlung to the background of lead shielded gamma spectrometers**, D. Mrđa, I. Bikit, M. Vesković and S. Forkapić, *Nuclear Instruments and Methods in Physics Research Section A*, Volume 572, Issue 2, 11 March 2007, Pages 739-744

[21] **Production of X-rays by cosmic-ray muons in heavily shielded gamma-ray spectrometers**, I. Bikit, D. Mrda, I. Anicin, M. Veskovic, J. Slivka, M. Krmar, N. Todorovic and S. Forkapic, *Nuclear Instruments and Methods in Physics Research Section A*, Volume 606, Issue 3, 21 July 2009, Pages 495-500

THIS PAGE INTENTIONALLY LEFT BLANK.

APPENDIX A. FREQUENTLY ASKED QUESTIONS

During nearly 30 years of ANGLE development, we have had extensive communication with, and feedback from, hundreds of ANGLE users. This chapter is the result of that valuable and highly appreciated experience. Queries, questions, doubts, comments and suggestions have been collected, selected and prepared so as to be of general interest not only to current ANGLE users, but also to those just having a look at ANGLE.

A.1 INSTALLATION

What software/hardware requirements do I need to be able to install and use ANGLE?
ANGLE 5 is compatible with all 32-bit or 64-bit versions of Microsoft Windows from Windows XP to the latest ones. There are no other system requirements. Faster processors are recommended, thus reducing calculation times.

I already have ANGLE installed, but I would like to reinstall it. Do I have to remove my current version before reinstallation?
No. simply re-run the installation file and ANGLE will update your existing copy.

Will I lose my data after reinstallation?
No. all your data will be preserved.

I downloaded ANGLE from your site, but I cannot install it.
This is most probably due to security restrictions on your computer/network. You might not have the right to install software on your computer. Please contact your system administrator for help.

We placed ANGLE and all of its files on a server disk accessible to all computers in our lab, so we can run it from the different computers and create new detector data. Is this the right way to centralize the model data of ANGLE?
No, that **would not be the best way to use ANGLE** since you will not be able to register it properly this way. The proper way is to install and register ANGLE on each computer separately (the number of installations depend on the number of ANGLE licenses you have). You can use the import and export function to easily share your parameters (e.g., for your detectors) from one computer to another.

A.2 REGISTRATION

Why do I need to register ANGLE?
ANGLE is commercial software. Unregistered copies will work in demo mode with all functions enabled, except efficiency calculations (if you are using ANGLE 5 or ANGLE 4, you will be able to run calculations with demo detectors). This is aimed at making you familiar with the software as well as for demonstration and even teaching purposes.

In order to unlock the calculations option, registration is requested.

We have five computers in our lab. Can I install ANGLE on all of them?
ANGLE can be freely downloaded and installed on any computer. To be able to run calculations, though, you need to register it.

I installed ANGLE on all the computers in our laboratory. Can I register it on all of them?
The ANGLE license is intended to be used on a single computer. When you reinstall your computer or make some hardware changes on your computers ANGLE must be registered again in order to be fully operational. Therefore, we allow up to three registrations per one year. Thus, technically you can (mis)use this allowance to register ANGLE on three computers, but that would be a violation of the license conditions. Besides that, if doing so you would not be able to re-register it in case of system change.

How can I register ANGLE?
You can register ANGLE in two ways: online (automatic) and via email.

First, you have to open and fill in the Registration form by clicking on the "Register ANGLE 5" option from the "Help" ribbon tab. Mandatory fields are marked with the asterisk ("*").

If your computer is connected to the internet simply click the "Register online" button and your copy of ANGLE will be registered. If not, you can register it by email. By clicking on "Register by email", ANGLE will automatically create an email for you with all registration parameters. You can also copy the registration information to Clipboard by clicking the "Copy to Clipboard" button and paste it to other application (e.g., text editor). Please send us an email with the registration data from a computer with internet connection and we will send you back the unique registration number which will unlock your copy of the software. When you receive the registration number, open the registration form again, click the "Enter registration number" button and enter the registration number you received from us.

My computer is connected to internet, but I cannot register online.
This is most probably due to security restrictions on your computer/network. For example, your antivirus/firewall software might block ANGLE accessing internet, or your system administrator removed some privileges. Please contact your system administrator for help or, simply, register ANGLE by email.

Also, depending on the internet connection you are using on your computer, it might be necessary to change the setup of the proxy server. ANGLE will, by default, use the proxy parameters defined in the system, but you can set parameters manually, or disable the proxy from the configuration dialog box. If you are unsure about proxy parameters, please consult your system's administrator.

I have downloaded ANGLE from your web site, but the software is asking for a serial number that I don't have. Please tell me what I should do.
When you install ANGLE, it will work in demo mode. In order to unlock the calculations option, you must be registered. We will provide you with the serial number together with your license, once you obtain it.

We installed and registered ANGLE on one computer in our lab. We shared the folder so we can access it from another computer, but we cannot run calculations from it. Can we use the same registration key?
It is not possible to "centralize" the registration – the registration of one computer will unregister a previously registered computer and you will also lose one of the limited annual registration attempts. ANGLE should be installed and registered on each computer separately (the number of installations depend on the number of ANGLE licenses you have). You can use the import and export function to easily share your parameters (e.g., for your detectors) from one computer to another.

A.3 CONFIGURATION

After installing ANGLE, I realized millimeters are used as the unit of length. Can I use some other units?
Yes. Millimeters are the default unit of length, but in the configuration dialog box, you can also choose centimeters or inches.

What will happen to my data if I switch between the units of length?
All parameters will be preserved, because ANGLE automatically performs any conversion to and from the units you have selected.

How about using ANGLE in other languages than English?
ANGLE 5 is a multi-language application. You can easily switch among the different languages anytime, from the configuration dialog box – just select the one you prefer from the Language drop-down menu.

Is it possible to add another language to ANGLE?
Yes. If you are willing to help us translate ANGLE strings to your language, we will gladly do it. It is not a tremendous task – about seven hundred strings, most of them just a few words long.

Can I change the default location for ANGLE files?
Yes. By default, ANGLE files are saved to the "ANGLE" folder, which is located in your *Documents* folder. Different file types are saved in a different sub-folder under this folder. This default location can be changed by clicking on the ellipsis button in the right-hand side of the "Default location for ANGLE files" group in the configuration dialog box.

My network uses specific proxy settings. Can I define them in ANGLE?
Yes. By default, ANGLE will use the proxy parameters defined in your system. If you want to override these settings, in the configuration dialog box you can choose whether you want to use proxy settings defined in your operating system, use no proxy server, or to manually enter the address and port values of your preferred proxy server.

A.4 DETECTOR

My company has three detectors. Do I need three copies/licenses of ANGLE?
No, one copy will be enough. ANGLE has no limitations regarding the number of detectors you can define.

We have detectors from ORTEC/AMETEK/EG&G/Canberra/PGT/other. Can we use ANGLE with them?
Of course. You can use ANGLE with any semiconductor (Ge) or scintillation (NaI) detector, regardless of the manufacturer. You just need to have a detector datasheet showing the characteristic detector dimensions and materials used.

Do we need to send our detector to you/manufacturer to characterize it?
No. The only thing you need for characterization is the detector datasheet showing the detector dimensions and materials used. Just enter these data in ANGLE and your detector is characterized immediately! Of course, in order to get the final result, i.e., to calculate detector efficiencies for particular counting arrangements, you need, in addition, to experimentally obtain a reference efficiency curve for your detector (efficiency transfer principle).

I am inputting my detector's dimensions in ANGLE but I am puzzled with some of the detector's data terms in the datasheet supplied by the manufacturer.

Indeed, there is no exact/consistent terminology in the literature and among manufacturers for particular detector construction details – different names are often used for the same thing. For example, "housing" could be also a "mount cap", "inactive Ge layer" could be named "dead layer" or "outside contact layer" etc. In order to avoid ambiguity/confusion/misunderstanding, ANGLE always – while entering/editing/reviewing the data – displays a schematic drawing representing the data being currently entered. While entering the dimensions, a red dimension line is showed on the illustration indicating the required dimension. Thus, it is important what is actually indicated this way on the detector drawing, and not what it is called.

We usually protect our detector by putting a plastic bag over it during the measurements. Can we define this bag in ANGLE?

Yes. You can define up to four additional absorbing layers in your geometry. Additional absorbing layer is any material gamma-rays encounter on their way from source to detector. For each layer you can define its top and side (relative to the detector) thickness and material.

I would like to create data for a new detector based on an existing one. Do I have to re-type all data again?

No. Just choose the detector you would like to use, click "Edit", change whatever you want, click the "Save as" button and give a name to the new detector.

This can also be applied to simply vary the parameters of the same detector towards its better characterization ("optimization") – for example, to estimate the real values of some parameters which are not directly accessible/measurable (dead layers, vacuum dimensions) by comparing ANGLE calculations with experimental data (measurements).

We have planar detector with core, but it is not possible do define core with planar detector in ANGLE. What should we do?

Technically, all cylindrical detectors have similar configurations. You can, without any worry, use the option for the equivalent coaxial detector (e.g., "closed-end coaxial"), just be sure to enter the correct dimensions.

Does ANGLE perform calculations for GMX type detector?

All GMX type detectors belong to "Closed-end coaxial HPGe" in ANGLE detector specification – they essentially have the same configuration. If the detector is made of (high purity) Germanium, then just choose the one which configuration corresponds to those of your detectors (consult the drawing ANGLE provides).

Can we change some parameters of demo detectors?

No. Demo detectors are there for demonstration purposes and you cannot change their parameters.

It looks like my detector's calibration isn't good anymore because the dead layer drifted into the crystal. Is that a problem given that I am using ANGLE now?

In principle, when detector characteristics change (worsen) due to ageing (dead layer drifting), then efficiency curve changes/shifts as well, normally to lower values, and especially at lower energies. You should just re-calibrate your detector, obtaining a new reference efficiency curve (REC) and go on. That's all!

I have noticed my HPGe detector crystal axis is shifted/tilted within the end-cap. Does it affect the accuracy of efficiency calculations? What can I do about that?

ANGLE does not support that. However, this effect usually does not have any dramatic effect. Recommended reading: Literature [17].

A.5 CONTAINER

How many different containers I can define?
You can define as many containers as you want. ANGLE has no such limitation.

I am inputting my container's dimensions. Please advise what should be written in every of these fields.
In order to assist with data entry ANGLE – while entering/editing/reviewing the data – always displays a schematic drawing representing the data which is currently being entered. While entering the dimensions, a red dimension line is showed on the illustration indicating the required dimension. So, simply look at the schematics while entering the data.

If a Marinelli beaker is used as the container, what exactly is the source height?
It is always the height of the active (radioactive) substance in the container, as illustrated by two typical cases here:

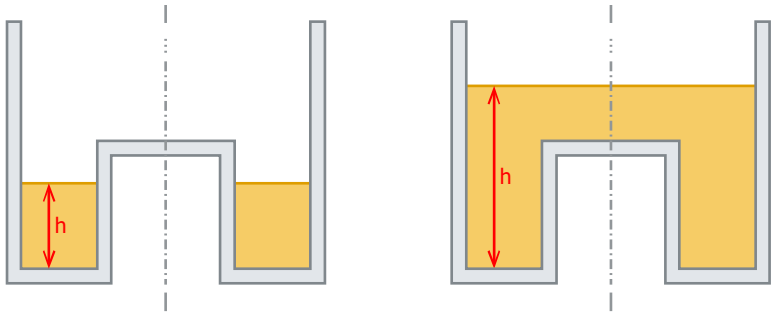

Figure 76. Marinelli Source Height

We are working on a paper about optimizing source size. Therefore, we have to vary a container's dimensions for each new container. Do we have to re-type all the data again, or can we reuse the existing container?
No. Simply choose the container you would like to use, click "Edit", change whatever you want, click "Save as" button and give a name to the new container.
This can also be applied to simply vary the parameters of the same container – for example, to find the optimal container size or volume.
ANGLE 5 allows for an even more flexible and powerful method – by utilizing its new XML-based file format and command line parameters.

Contact pin dimensions/material is not specified in my detector datasheet. What should I do?
Contact pin data are not critical in ANGLE calculations. If not specified in the datasheet, we suggest that you take some standard pin diameter and material data from the same detector manufacturer (e.g., 2 mm, copper).

A.6 GEOMETRY

How many different geometries I can define?
You can define as many geometries as you want. ANGLE has no such limitation.

I am inputting data for my geometry. What should I write in those fields?
In order to assist with data entry ANGLE – while entering/editing/reviewing the data – always displays a schematic drawing representing the data which is being currently entered. When entering the dimensions, a red dimension line is showed on the illustration indicating the required dimension. So, simply look at the schematics while entering the data.

How do I define a source which is located/suspended at some distance to the detector but not placed on a holder?
Although you do not actually use a holder, you can still define a "virtual" one, in order to account for the distance between the source and the detector. Just define a holder with a cap thickness equal to zero and a radius bigger than both the detector and source. The only thing you will have to precisely define is the holder height, which will then represent the actual distance between the source (or its container, if present) and the detector.

What is the additional absorbing layer?
The additional absorbing layer is any material encountered by gamma-rays on their way from source to detector, e.g., a plastic bag over the detector's end-cap (commonly used to protect from contamination). For each layer you can define its top and side thickness and material.

Does absorbing layer thickness increase the distance between the detector and source?
Yes. The distance between the detector and source is automatically increased by the sum of the top thicknesses of all defined absorbing layers. In other words, the holder and/or container (if any) are put on top of those layers.

I would like to create a new geometry similar to one I have already entered. Do I have to re-type all the data again, or can I use the existing geometry somehow?
No. Simply choose the geometry you would like to use, click "Edit", change whatever you want, click on the "Save as" button and give a name to the new geometry. A good tip for the counting optimization or error propagation studies!

A.7 SOURCE

Can I define point and disk sources? These are not explicitly offered in ANGLE source options.
Yes. For disk sources just enter zero for the source height. For point sources enter zero both for height and radius. You may notice that ANGLE will perform the calculations much faster in these cases, than for a cylindrical or Marinelli source.

Do I need to know the composition of the material of my source?
Yes (except if you are using point or disk sources). It is very important to know as good as possible the materials of your whole configuration (including the source, its container, detector construction details, absorbing layers etc.), because it is an essential parameter for the calculation of gamma-ray attenuations (self-attenuation in case of source). However, it is not necessary to know the exact composition of the materials – only the knowledge of the major constituents would be enough, while those in trace quantities does not matter really (this is because in ANGLE material composition accounts for gamma-attenuation).

My source is "self-standing", in form of a solid pill, i.e. I do not need a container to place it in. Can ANGLE handle this situation?
Yes. Simply select the "No container" option in the "Geometry" frame.

My source is in the form of a solid pill placed in a container – the pill radius is smaller than the container inside radius. Can ANGLE handle this situation?
Yes. Simply click the "Source radius" option in the "Source" group of the main window and enter the value you want. This radius, of course, cannot be greater that the container's inside radius.

I am studying the properties of some spherical coated sources. Does ANGLE support that?
No, ANGLE does not support spherical sources. Nevertheless, if there is an explicit user's request to do this, such an option can be considered/developed.

I am counting cylindrical sources positioned perpendicularly to the detector axis. Can I use ANGLE to calculate detection efficiency?
No, ANGLE does not support cylindrical sources positioned perpendicularly to the detector axis. Nevertheless, if there is an explicit user's request to do this, such an option can be considered/developed.

Our container's walls are not vertical, but slightly slanted. Can we somehow approximate this in ANGLE?
ANGLE currently supports only vertical container walls. If you want to approximate your container with the cylindrical one, we suggest you define the radius of the cylindrical container so that the volume and height of the source remain unchanged. Please note that a different height of the source would lead to another approximation for the container's radius.

A.8 REFERENCE EFFICIENCY CURVE (REC)

Why do I need to define the REC?
The reference efficiency curve (REC) is absolutely crucial, since the efficiency transfer (ET) principle applied in ANGLE is based upon it. All your actual detection efficiencies are calculated by comparison to it at corresponding energies. If the reference efficiency curve is not specified, these efficiencies will not (cannot) be calculated (only effective solid angles will be calculated in that case)!

Obtaining a reliable reference efficiency curve is thus essential for successful ANGLE utilization: all ANGLE results for a given detector will be relative to REC with an error propagation factor = 1 (that is to say 100% of the uncertainty in the REC is added to the uncertainty budget of the calculated efficiencies).

The investment of time and care in determining a reliable REC will always pay off!

We strongly recommend reading [1], [2] and [12] in the Literature to become more familiar with the subject.

I understand that REC and its quality are crucial for good calculation results. What should I bear in mind when preparing REC for my detector?
Correct. Calibration sources should cover the gamma-energy region of analytical interest (e.g., 50-3000keV). It is suggested that calibrated sources with low certified uncertainties (not exceeding 1.5%-2.5%) are used to obtain as many calibration points (efficiencies vs. gamma-energies) as possible for the energy range mentioned. This non-negligible initial effort is largely paid back in future exploitation since an accurate reference efficiency curve is fundamental for accurate ANGLE application.

How many experimental points should I have?

The more experimental points you have, the better your REC will be. It is recommended to have at least 20 points for a good curve.

I have data for my RECs experimental points in an Excel/text file. Do I have to type in those values in ANGLE one by one?
No. Simply select the data in your document, copy it, go to ANGLE and press "Paste from Clipboard".

How many gamma-energy regions should I define?
ANGLE interpolates the REC using the experimental points you defined. To make as good a fit as possible it is advisable do divide the REC in two or more regions, e.g., one where the REC is almost linear and the other one where it is not. For each region you can define the fitting polynomial order to be sure the final REC will follow the experimental points correctly. At joint points, the curve will be smoothened.

How wide could my regions be?
The regions should be well covered with experimental points. It is not a good idea to extrapolate the regions much beyond the area covered by experimental points. For example, if the lowest energy point is at 88 keV, one should not start the first region at 20 keV. Otherwise, the resulting efficiencies for low energies might not be accurate.

Can I define more than one REC?
Yes. There are no limitations regarding the number of RECs in ANGLE. Once you define your REC you can save and use it anytime later. You can obtain different RECs for the same detector by varying calibration sources and/or counting distances.

We have two detectors. Should I define RECs for both of them?
Absolutely. The reference efficiencies for different detectors are not the same, even if they are the same type! Each detector should have its REC in order to obtain a correct calculation result. Data from one detector cannot be used for calculating the efficiencies of the other.

Do I have to use exclusively point source(s) for my detector's REC?
No. Any calibrated source(s) can serve to obtain a REC. However, when the quality (uncertainties) of output data is of great concern, it is advisable to have a REC which is produced from calibration source(s) geometrically not much different from the sample for which ANGLE calculations are performed. In doing so, error propagation will be reduced, and the results will be more accurate.

Is it OK to have more than one REC for one detector? If yes, why?
One REC per detector is enough, in principle. It is recommended to construct it by counting the number of calibrated point sources at a large distance from the detector (e.g., 20-30 cm), avoiding true coincidences and matrix effects. In addition, absolutely calibrated point sources are often certified to a better accuracy than voluminous ones.

It is generally more prudent to use **several single-nuclide sources**, than a single multi-nuclide source.

However, in order to additionally exploit the ET error-compensation effect, one might consider constructing more RECs for the same detector. For instance, the same point source(s) counted at a large distance could also be counted on the detector top, yielding another REC. Calibrated cylindrical and Marinelli sources could produce additional RECs.
In an ideal case, using any of several RECs in ε_p calculations would produce the same result for the actual sample, i.e., the result should be independent of the choice of REC. However, given the fact

that all input data (detector, source, geometry) are inaccurate to some extent, choosing a "likely" REC for the actual sample/geometry should eventually produce better (more accurate) results, due to larger ET error-compensation effect. In other words, if the REC sample/geometry is closer to the actual sample, the results will tend to be better.

This in itself is a measure of the accuracy of the various sample and detector parameter choices – if two RECs produce results which are close, the implication is that both sample/geometry and detector are well characterized.

I have created a REC and saved it to file. How can I load it back since I changed it in the meantime?
Open the "Reference efficiency curve" dialog and click on the "Load saved curve" button. Choose the file with the name under which you saved the REC and click OK.

Another, more flexible way, to select a previously saved REC is using the pop-up menu, which you can open by clicking the "Reference efficiency curve" label in the "Additional parameters" group of the main window. Choose the option "Saved curves" and select the previously saved material from the sub-menu.

Can I load the experimental points from ORTEC's GammaVision?
Yes. Open the "Reference efficiency curve" dialog and click on the "Import from GammaVision" button. Choose the EFT file which you saved from GammaVision and click OK. The interpolation parameters will also be imported, check them and modify, if you want.

Can I load the experimental points from Canberra's Genie 2000?
Yes. Open the "Reference efficiency curve" dialog and click on the "Import from Canberra CAM file" button. Choose the CAM file which you saved from Genie 2000 and click OK.

I would like to create a new REC based on an existing one. Do I have to re-type all data again?
No. Simply change whatever you want, enter the new name for the REC and click OK. You will be prompted if you would like to save the REC. It is a good tip to use this possibility when investigating/improving the quality of a REC by adding/removing/adjusting experimental points in the REC.

We are measuring gaseous samples in large Marinelli beakers. It is very expensive to have the Gas Marinelli calibration source for the REC (this is why we wanted to use ANGLE in the first place). Is it possible to use another Marinelli geometry (e.g., smaller and liquid/solid) for the REC? I assume this would still be a better idea than using point sources?
Definitely, any Marinelli standard would do it better than point ones for the REC in this case. This is because of the dominant contribution of the geometrical solid angle in the effective solid angle (the latter being directly related to the calculated efficiency).

If you do not have a Marinelli standard to hand, any large cylindrical standard, measured at the top of the detector, might still be a closer match to the gas Marinelli sample(s) than point ones.

To be well understood, there is nothing especially bad about neither the point sources, nor the ANGLE principles – it is all about the propagation of (inevitable) uncertainties in input data. Thus, point calibration sources would work as well if you do not have a better match.

Do I need to use interpolation? Could I just stick with the exact reference efficiencies for the given energies?

You can stick to your experimental efficiencies at particular gamma-energies. Namely, in ANGLE 5 you can define a "discrete curve". If you do not specify interpolation regions (i.e., if you enter "0" as the number of regions), interpolation will not be used. You will not be able to calculate efficiencies for energies defined by your REC's experimental points, and their exact efficiency values will be used (leading to better accuracy for the given energies). This possibility may be particularly useful with NaI detectors.

Can I see the polynomial coefficients and other interpolation parameters for my curve?
Yes. In ANGLE 5 it is possible to see the calculated polynomial coefficients and other interpolation parameters. To see this, click on the "Interpolation data" button in the "Reference efficiency curve" window. You can select and copy parts of the data to another application or click on the "Copy to Clipboard" button and copy all at once.

Also, ANGLE inserts calculated polynomial coefficients in the form of a comment in calculation parameters and calculation results files, so you can read them from other applications as well.

I use my NaI detector for Cs-137 determination in samples only. Is it necessary to have a REC?
No, in that case you can use a reference calibration with whatever Cs-137 standard you have, thus at 661.6 keV energy only ("REC discretization"). This is a great practicality introduced in ANGLE 5.

How shall I construct REC for NaI detector?
For NaI detectors we recommend "REC discretization", i.e., to have several calibration points at particular ("discrete") energies of interest. Much better accuracy is achieved in that way. Of course, you will not be able to calculate efficiencies for any other energy than those few specified. Usually, this is not required with NaI.

Nevertheless, REC can be constructed the same way as for Ge detectors. Not so many experimental points can be considered though since peaks are broad and tend to overlap. More single-nuclide (preferably single-gamma) calibration sources are advised rather than a single multi-nuclide or a multi-gamma source.

Apparently, one should not expect the same REC performance with NaI detectors as with Ge ones.

A.9 MATERIALS

I have to calculate the efficiency for my soil sample, but ANGLE does not give me soil as an option when choosing source material. What should I do?
You can define any custom material, as long as you know its composition data and density. When choosing the material, choose "Specify material..." option and define your custom material. You will be prompted to save it to disk, if you want, to be able to re-use it later.

The reason ANGLE does not offer "soil" as a typical source material is because of the diversity of soil types, the composition of which varies considerably – so it is up to the user to define it.

How is sample humidity accounted for in material composition?
The safest way is to have dry samples, without any humidity. In the case of humidity, the quantity (in %) should be known and simply entered in the material composition (choose mixture of compounds, with water being one of them with appropriate mass percentage).
How can I define my material?

Depending on the material, it can be defined in three ways: as a mixture of elements (you have to define element symbols and mass percentages), as a compound (you have to define element symbols and number of atoms) and as mixture of compounds (you have to define each compound separately and the mass share percentage). In either case you have to define the density of your material and the material name. You can save the material to disk for later use.

I defined the parameters for a sulphuric acid mixture a few days ago. In the meantime, I used other materials and now I need it again, for another calculation. Do I have to define the material again?
No, if you previously saved your material to disk. Simply click on "Specify material..." when choosing the material, click the "Load saved material" button and select the material you saved.

Another, more flexible way to select the previously saved material is by using the pop-up menu, which you can open by clicking the "Source material" label in the "Source" group of the main window. Choose the option "Saved materials" and select the previously saved material from the sub-menu.

How accurately I need to know the material composition?
The more accurately you know it, the better, because this information is input for gamma-attenuation calculations. However, minor constituents (e.g., trace elements) in the material do not contribute considerably in this sense and can be easily omitted if not known. In any particular case, you may verify (by trial calculations) how the absence/presence or concentration variation of a given component is reflected in your final result.

When entering material composition, ANGLE requires that the mass sum of the constituents is 100%. If you are omitting some minor constituents, the sum might come to (a bit) less than 100%. In that case, it is advisable to add the difference to the major constituents you entered, proportionally to their presence.

How can I measure the density of the material?
You simply measure the mass and the volume, and the density is the ratio of the two. Pay attention to enter density in g/cm^3 when defining the material(s) in ANGLE.

Can I simply type in the chemical formula of my material?
Yes. In ANGLE 5 you can enter the compound using the chemical formula – simply type it in the "Chemical formula" box and ANGLE will automatically break it down to element symbols and the numbers of atoms.

A.10 ENERGIES

Can I define any energy set, or I must stick with those energies defined in REC?
You can define any energy set you want (you don't even have to have a REC defined to run calculations). Please pay attention that, when you use a REC for calculations, all energies you are interested in must fall inside the regions defined in that REC (that's if you defined them, i.e., if you are not using discrete curve).

I have all my energies in an Excel/text file. Do I have to type them again in ANGLE, or is there a faster way to do that?
There is a simple way to do that. Select the data in your document, copy them, go to ANGLE and press "Paste from Clipboard".
We would like to perform calculations for energies from 3 keV to 3000 keV. Can ANGLE do this?

ANGLE support energies from as low as 0.1 keV to 100 GeV (10^8 keV). However, in low gamma-energy region (say below 50 keV), attenuation becomes so intense that detector geometrical and compositional data cannot be specified accurately enough to enable the same quality of results as for higher energies. Above 2000 keV reliable calibration points are scarce, so in this region RECs are generally poor, limiting ANGLE's practical applicability. Using ANGLE (like any other software based on absolute or semi-empirical efficiency calculation method) in very low and very high energy regions should thus be carried out with this in mind and with the utmost care.

"Discrete REC" option, though, enables this limitation to be greatly overcome, thus ANGLE energy region of practical applicability considerably expanded, thanks to ET error-compensation effect.

I created a new set of energies and saved it to file. How can I load it back, since I changed it in the meantime?
Open the "Energies" dialog and click on the "Load saved energies" button. Choose the file with the name under which you saved the energies and click OK.

Another, more flexible way to select the previously saved energies is by using the pop-up menu, which you can open by clicking the "Energies" label in the "Additional parameters" group of the main window. Choose the option "Saved energies" and select the previously saved energy set from the sub-menu.

A.11 CALCULATIONS

What is the "Save calculation parameters" option here for?
The "Save calculation parameters" option collects all current parameters (selected detector, container, geometry, source, energies, REC data and calculation precision) and saves it to a file. This is convenient in many cases, such as: when calculations will not be performed immediately, for preparing the calculations which will be performed on another computer or for preparing the inputs for multiple calculations at the same time (batch jobs). ANGLE 5 allows for a flexible and powerful method of automating multiple calculations, by utilizing its new XML-based file format and command line parameters.

Can I save calculation parameters and use this file for calculations on another computer?
Yes. The saved file contains all the needed information, so it can be used for calculations on any other computer with ANGLE installed.

I am trying to save the calculation parameters to file, but I am receiving an error message.
Before saving, ANGLE checks all input values for possible incompatibilities. If there is an incompatibility in input parameters, such as an invalid detector-container combination (for example when using a well detector with a Marinelli container, or when using REC form one detector to perform efficiency calculations with another), the error message will be shown. You should check your input parameters.

What does the output of the calculations mean (from what I can see in the output file)? How does this output then give me the nuclide concentrations I am looking for?
The output gives you the effective solid angles and detection efficiencies for a set of gamma-energies you choose (which means the set of gamma-energies you are interested in with your sample).

From the detection efficiencies, the calculation of the activities (or concentrations) of the radionuclides present in the sample is straightforward: there is a simple linear proportionality between the detection efficiency, number of counts in the particular full energy gamma-peak (peak

area), gamma-line intensity (emission probability), live counting time, and activity (or, proportionally to it, concentration). Gamma-line intensities are well known nuclear parameters, while peak areas and live counting times represent the experimental evidence (result of gamma-counting, called gamma-spectra).

From the effective solid angles only (thus without REC – a reference experimental counting), activities (concentrations) of the radionuclides in the sample cannot be obtained.

Resulting precisions for all energies are different, why?
The calculation precision varies depending on the energy. ANGLE proceeds with calculations until the specified target precision is met for **all** of the specified energies, meaning that the worst-case result will be just below the specified precision (typically for the lowest energy), while it will be better for other energies.

I specified 0.5% as the target precision. The precisions for the calculated effective solid angles meet this condition, but efficiency precisions for some energies are higher than this. Why?
The calculation precision is used for effective solid angle calculations. Efficiency calculations involve two such calculations (one for the sample and the one for the reference geometry), thus the total precision is calculated as a square root of sum of squares of these two precisions for each energy. This means that in your case the efficiency precision can be up to 0.7%, i.e., $0.5\% \cdot \sqrt{2}$.

Why is my worst-case result around 0.8%, although I set the target precision to 1%?
ANGLE will stop iterating calculations when the target precisions for all specified energies is met, but not before it finishes certain number of iterations, in order to be sure that the results are stable. Therefore, in some cases this will lead to better precision than the one which is specified.

I changed some parameters of my calculation parameters (detector, container, geometry, source, REC, calculation precision), but I'm still getting the same calculation results!? Why?
Most probably you are performing calculation from files saved prior to the changes you made. If your input parameters are changed after saving the calculation parameters to file(s) the file(s) will still contain the previously defined parameters. Run the calculation from the current data instead or save the input parameters again and run calculations from newly saved file(s).

I tried to run calculations from file, but I am receiving warning saying that the file is created with a higher version of ANGLE than the one I am using.
You are trying to run calculations from file created on another computer and you are using ANGLE with version lower than the one on that computer. Some of parameters specified in this file might be ignored or misinterpreted.

I am trying to run calculations/save input parameters, but I keep receiving a message that ANGLE is not registered. Am I doing something wrong?
Unregistered copies of ANGLE will work in demo mode with all functions enabled, except efficiency calculations (if you are using ANGLE 5 or ANGLE 4, you will be able to run calculations with demo detectors). In order to unlock the calculations option, you must be registered. Please fill in the registration form, using the serial number you got with your copy of ANGLE and register it using one of the several available methods.

Can we somehow try the calculations in ANGLE before we decide to obtain licenses?
Yes. ANGLE 5 comes with a set of eight predefined demo detectors, one for each supported type. You can use them for calculations even in demo mode, i.e., even if ANGLE is not registered. This way

you can evaluate the results, so as to become more familiar with software scope and capabilities – without/before being registered.

Demo detectors are also very useful for educational/training purposes. Now ANGLE is there for everyone as a free educational/training tool. For example, it can be used for studying the impact of particular parameters characterizing the detection process on the detection efficiency; or, just to experience/train gamma-spectrometry practice.

My calculations are finished, and I have got the results. Can I use these results in another application, e.g., spreadsheet or word processing software?
Yes. Just click on the "Copy to Clipboard" button and paste the values in the application you want. This is very convenient for various studies applying ANGLE output data.

ANGLE saves the calculation results in the XML files with the ".outx" extension. These files can be imported in any third-party application which can handle XML format.

Additionally, it is possible to save the results in two more popular formats: JSON and YAML. This makes the number of possible applications even bigger.

Also, you can export your results directly to ORTEC's GammaVision or Canberra's Genie 2000.

Can I see the parameters used for calculation?
Yes. You can see any input parameter used for calculation. For example, if you want to get information about the detector used, simply click on the detector name or the information button next to it.

Can I print the calculation results?
Yes. If, while viewing the results, you want to print them, just click the "Print calculation results" button to print a one-page document containing the results together with a summary of all the input parameter data, counting arrangement schematics, as well as the calculated efficiency curve (if calculated).

A detailed report can be printed by clicking the "Print calculation report". The report will contain the results, as well as all the input parameter data used in calculations – thus **making the results traceable to the input values**.

Can I save the calculation results/report to a document, for example to a PDF?
Yes. The procedure is the same as for regular printing. You just have to choose a virtual PDF printer when printing. If you need help to install PDF printer software, please contact your system's administrator.

How about traceability of calculation results?
You may notice that a detailed report can be printed by clicking "Print calculation report". The report contains not only the results, but also all the input parameter data used in the calculations – thus **making the results traceable to the input values**. This implies that the quality (accuracy) of calculation results depends primarily on the quality (accuracy) of the input parameter data.

If you may wish to gain a better insight into the specific "error propagation" of a particular input parameter (e.g., crystal radius, or dead layer thickness, or source matrix composition...) towards the final calculation result (efficiency), we advise using ANGLE 5 applicability for research purposes. Suggested reading: [3] in the Literature.

Traceability is an important issue when validating analytical methods and/or accrediting the labs. You will surely find the above helpful in that sense.

We are working on a study in which we are analyzing the impact of certain input parameters on efficiencies. We have carried out a great many calculations. Can we open all the calculation results files at once?
Yes. Click on the "View calculation results" button on the "Calculations" ribbon tab, select all calculation results files you would like to open and click on the "Open" button. Now you can simply move from one calculation results file to another.

If I send a calculation results file to another computer with ANGLE installed, can they open it?
Yes.

I am evaluating ANGLE and I am still using the demo copy. I know that I cannot perform calculations, but can I open a calculation results file from another computer?
Yes. You also have demo output files already installed with ANGLE – try them.

Can I use my calculation results for efficiency calibration in ORTEC's GammaVision?
Yes. While viewing output results, click on the "Export to ORTEC GammaVision" button. A new dialog will open where you can choose if you want to export ORTEC GammaVision efficiency calibration file (*.EFT), or geometry correction file (*.GEO). In the latter case you can also specify the uncertainty. After clicking the "OK" button you will have to choose the name and location of the exported file. This file can subsequently be imported in GammaVision.

Can I use my calculation results for efficiency calibration in Canberra's Genie 2000?
Yes. While viewing output results, click on the "Export to Canberra CAM file" button and choose the name and location of the Genie 2000 CAM file.

I am trying to export calculation results to GammaVision, but the "Export to ORTEC GammaVision" button is disabled.
This is because you calculated only effective solid angles, not efficiencies, which are required by GammaVision. In order to calculate efficiencies, you must specify a reference efficiency curve for your detector.

I am trying to export calculation results to Genie 2000, but the "Export to Canberra CAM file" button is disabled.
This is because you calculated only effective solid angles, not efficiencies, which are required by Genie 2000 In order to calculate efficiencies, you must specify a reference efficiency curve for your detector.

I have successfully run the calculations, hit the "Export to ORTEC GammaVision" button and saved the EFT file. How can I load this file into GammaVision?
Start GammaVision and select the specific detector for which you want to create the new efficiency calibration, using the detector pull-down menu on the toolbar. Next select the option "Calibrate" and then select "Efficiency". When the "Efficiency Calibration" window opens, click on the white box on the upper left of the sidebar and select "Destroy" from the control menu which will remove any current efficiency calibration data. Then click the "Merge" button, browse for and select the EFT file created by ANGLE.

At this point it is possible to change the fitting mode for the efficiency data transferred from ANGLE, as the default fit type is linear, using the "Mode" section of the "Efficiency Calibration" window. Once you have closed the "Efficiency Calibration" window, select "Save Calibration" from the "Calibrate" option and save the new calibration file.

I am trying to import/export calculation results from/to Genie 2000, but I am getting the warning that Genie 2000 is not installed on my computer.
ANGLE requires Genie 2000 to be installed on your computer to be able to import or export CAM files.

Can I use Marinelli sources with well detectors?
Even though it is physically possible to count Marinelli sources on well detectors (assuming a Marinelli cavity larger than the detector end-cap), ANGLE does not support that option; we considered it strange to utilize a highly specialized well detector in just the opposite way as it was conceived/designed for.

Nevertheless, if there is an explicit user's request for this, such an option can be considered/developed.

A.12 UPDATING ANGLE

Why do I have to update ANGLE?
You don't, but it might be a good idea to do that from time to time. We are constantly working on improvements to our software, and we publish software updates accordingly. These updates usually bring new functionalities, improve the existing ones and fix bugs. Therefore, it is advisable to update ANGLE occasionally.

How can I update ANGLE?
It's easy. ANGLE has a built-in automatic updating function. So, if your computer with ANGLE is connected to the internet, just choose the "Check for updates" option from the "Help" ribbon tab and ANGLE will contact the update server over the internet to check if there are updates available. If yes, you will be prompted if you would like to install them or not.

Can ANGLE automatically check for new updates?
Yes. ANGLE has a built-in automatic update function. In the configuration dialog box just choose how often you would like ANGLE to automatically check for updates.

My computer is not connected to the internet. Is there other way to update ANGLE?
Of course. Just download the latest installation file from our site and use it to re-install ANGLE. There is no need to uninstall the current version beforehand.

My computer is connected to the internet, but I still cannot update ANGLE.
This is most probably due to security restrictions on your computer/network. For example, your antivirus/firewall software might block ANGLE accessing the internet and/or downloading files, or your system administrator removed some privileges. Please contact your system administrator for help or download ANGLE from our site and use this file for update.

Also, depending on the internet connection you are using on your computer, it might be necessary to change the setup of the proxy server. ANGLE will, by default, use the proxy parameters defined in the system, but you can set parameters manually, or disable the proxy from the configuration dialog box. If you are unsure about any proxy parameters, please consult your system's administrator.

I downloaded ANGLE from your site but I cannot update it?
This is most probably due to security restrictions on your computer/network. You might not have the rights to install software on your computer. Please contact your system administrator for help.

Do I have to uninstall my current version before updating it with the new one?
No. Simply run the installation file and ANGLE will update your existing copy.

Will I lose my data after update?
No, you will not lose the data. All your data will be preserved.

A.13 APPLICABILITY

How about ANGLE in situ applicability?
ANGLE is suitable for in situ measurements, e.g., for the determination of soil surface or in-depth contamination. An appropriate geometrical model/description should be applied to achieve that aim. For instance, a soil surface can be described as an infinite disk source, which practically means a couple of meters of diameter if the detector is put upside-down just above it (the rest does not contribute tangibly to the measurement), as is common in this type of measurement. In-depth contamination can be calculated by considering the soil as an infinite slab of a certain thickness (again, in practice, it is sufficient to take into account only a couple of meters around the detector).

I intend to study error propagation functions in quantitative gamma-spectrometry. How can ANGLE help me?
ANGLE is a great tool for automating your study. All files in ANGLE 5 are based on the XML format. You can modify or create them from your software. You can run them manually or automatically, using the command line parameters.

The easiest way, in your case, is to create one set of calculation parameters file in ANGLE, load it in your software and then just change the parameter(s) you want.

Can I use ANGLE to improve/optimize my laboratory performance?
Of course, based on thorough error propagation studies, for which ANGLE is ultimately suited, you can improve/optimize your laboratory output/performance

I am lecturing gamma-spectrometry to undergraduate students. How can I use ANGLE for this?
ANGLE is a great educational/training tool, as practically all relevant notions are grouped/systematized/visualized – either in the data input phase, or in the output.

Fully functional ANGLE will thus surely be enjoyed both by students and lecturers. Even a demo version (with 8 demo detectors of most common types) can be used for teaching purposes. Therefore, numerous universities worldwide have been ANGLE users from its beginnings.

I am a Ph.D. student in radioecology. How can I benefit from ANGLE?
ANGLE is useful at all educational levels, from lecturing gamma-spectrometry fundamentals, to extensive scientific studies. Its modular character enables it to be easily integrated with most sophisticated third-party software, both for input and output. We recommend reading further in the Literature [3], [10] and [11].

Our lab has very limited resources and we cannot afford to purchase ANGLE. Can we still use it somehow?

You can use ANGLE in demo mode. It is fully functional, only efficiency calculation is disabled. However, even calculations can be done with a number of demo detectors. Using this option, with some additional effort, you can estimate to a certain extent your actual detection efficiencies, and hence your source activities.

A.14 MISCELLANEOUS

We are developing software to study the impact of the source density for detection efficiency. Can we somehow automate the process of generating ANGLE input files, or we have to make all changes/variation of input parameters and calculations manually in ANGLE?
Yes, you can automate the process. All files in ANGLE 5 are based on the XML format. You can modify or create them from your software. You can run them manually or automatically, using the command line parameters.

The easiest way, in your case, is to create one set of calculation parameters file in ANGLE, load it in your software and then just change the parameter(s) you want.

I would like to use a preview image from ANGLE in my paper. There are four different formats to choose from. How to choose between them?
That depends on your needs. Most probably you would like to choose one of the vector formats for your paper, since they look better on paper. You can scale them without losing any quality and consume much less space on disk. You can even import them to vector graphics applications such as Adobe Illustrator or CorelDRAW and edit them freely.

Raster images may look better on screen and other low-resolution devices and are ideal choice for the web. The PNG format is optimal for preview images, but you can also export to BMP and JPEG formats.

I tried to save the preview image in the BMP/JPEG format, but the resulting image is too small/big. What should I do?
Raster images are saved using the current zoom factor, so the more you zoom it, the larger the resulting image will be. To adjust the size of your resulting image simply zoom it in/out until you reach the required level of details, and then save the image.

In any case, we suggest you use the PNG file format, since it is lossless and provides excellent compression for preview images***.***

I tried to send the reference energy curve/output file/saved file... in an email as an attachment, but I cannot find it. Thus, I can use it in ANGLE, but cannot manage to attach it.
ANGLE 5 saves, by default, all files in the "ANGLE" folder located in your *Documents* folder. You can see the location (and even change it) in the configuration dialog box.

You can also use a simple trick – when you see the list of files in ANGLE (for example when you click "Load curve from file" button), right-click on the file you want to share and select "Copy". Then you simply paste it to some other location temporarily (e.g., on the Desktop) and attach it from there.

We installed ANGLE on a new computer in our lab. How can we copy our detectors/ containers/geometries data, so we do not have to re-enter them on the new computer?
There are two approaches you can use. One is to export your detectors/containers/ geometries one by one and import them on the new computer.

The other approach is a bit more complicated but allows you to copy all the data at once. First you need to locate the files in which ANGLE keeps the data on the old computer. The names of these files are “Detectors.datx”, “Containers.datx” and “Geometries.datx”. Depending on the operating system, ANGLE version and the options used during the installation, they could be in different folder. Usually, you can find them in your *AppData*\Local\ANGLE folder. When you locate these files, you just need to copy them over the existing ones on your new computer. Be aware that by this you will overwrite the existing data, if any!

We installed ANGLE on a new computer in our lab. How can we copy our calculation parameters/calculation results/energies/materials/reference efficiency curves/ nuclide sets to our new computer?
ANGLE saves all these files in the “ANGLE” folder under your *Documents* folder. You can simply copy these files/folders to your new computer.

How does ANGLE compare to the relative method for the determination of sample activities?
ANGLE is a semi-empirical method for detection efficiency calculations; from detection efficiencies there is a single straightforward step (involving gamma-peak areas) to determining activities of the radionuclides present in the sample. ANGLE thus combines the advantages of both the absolute method (flexibility in application) and the relative method (high accuracy), while minimizing their drawbacks. When care is taken to ensure that the actual and calibration counting arrangements do not differ too much, the “quasi-relative” conditions are met and accuracies comparable to the relative method can be achieved.

Why do I need software at all for efficiency calculations? I have plenty of standards in my lab and I am happy with them.
The relative method, based on a simple comparison of samples to standards under the same counting conditions is the spectrometry “classic” – the method of choice. It is simple to apply, results are easy to calculate and, most importantly of all, the resulting accuracies are the best possible. For a while this will satisfy the user’s needs, but sooner or later it will be realized this approach is extremely rigid, requiring ever more standards (never enough), and eventually limiting laboratory performance. Just small differences in counting conditions between the sample and the standard (e.g., different source matrix, or a slight difference in the source container) will introduce systematic errors which cannot be accounted for. Also, any “new” gamma-line in the sample, not present in the standard, will be impossible to quantify.

Whatever valuable source of reliable fundamental information, the standards are not easy to handle (e.g., dilute), they are not cheap either, their activities are continually decreasing and hence have a limited working life, after which have to be disposed of. In addition, they have to be under regulatory control during their whole “cradle-to-the-grave” lifetime.

This rigid inflexibility is the main drawback of the relative method, and forms the main advantage of ANGLE, which is free of it altogether. In addition, there are many other advantages.

I learned ANGLE can be used in “quasi-relative” mode. What is that actually?
ANGLE is based on the efficiency transfer (ET) principle: from known detection efficiency (reference efficiency curve, REC), an unknown efficiency is calculated. In principle this works for any two counting arrangements (with the same detector, of course). There are uncertainties in input parameters (unavoidable), though, which are propagated to the final result (calculated efficiency). Error propagation factors tend to be smaller if the two counting arrangements are similar to each other. For instance, it is more favorable to calculate efficiency for a one-liter Marinelli source having

a REC of 0.5-liter Marinelli, than from a point source counted at 30 cm distance from the detector. This happens because uncertainties in such cases tend to compensate for this issue (error reduction/compensation effect). Extrapolating the error reduction effect to its limits, we arrive at the "quasi-relative" method, when both the known and unknown efficiencies differ only a little (as little as practically achievable). The difference is large enough that a proper relative method cannot be used, but small enough to enable ANGLE calculations to produce comparably good results (to the relative method); without doubt the relative method is the one which yields the most accurate results in quantitative gamma-spectrometry and the quasi-relative method is just behind it.

What is the error propagation factor?
In any gamma-spectrometric method (absolute, relative, semi-empirical...) there are input parameters needed for obtaining the final result – activities of radionuclides present in the sample. These parameters include numerous characteristics of the detector, source (incl. its container), and counting geometry. Uncertainties in the values of these parameters, as in any physical quantity, are unavoidable. One way or another, these uncertainties are propagated to the final result. The proportionality factor with which this propagation is made for a given counting arrangement is called the error propagation factor. Note that the term "error" here is not exact – it refers to the uncertainty, not an error in its proper sense.

What is the error propagation function?
The term error propagation function represents the variation of an error propagation factor with changes of some of its input parameters. In ANGLE, we speak of the error propagation function of calculated detection efficiency vs. changes in, for instance, detector crystal dead layer.

What is the difference between "detector efficiency" and "detection efficiency"?
Detection efficiency is a characteristic of the counting arrangement (the ensemble of the detector, source, container, including their geometrical positioning, and all absorbing layers). It is the probability that a photon (in this context: gamma or X-ray) emitted from the sample will be detected by the detector (and recorded by the accompanying equipment, e.g., multi-channel analyzer); apparently it depends on photon energy, detector and source characteristics, absorbing layers photon encounters, counting geometry, etc. Being a probability, it is a dimensionless quantity, fraction of 1.

Detector efficiency, also called relative efficiency, is a characteristic of the detector. It is defined as detection efficiency at 1332 keV of a Co-60 point source counted at 25 cm distance from the given detector, as compared to (the same with) 3 × 3" NaI detector. It is thus expressed in %.
Detection efficiency is, thus, a broader, more complex term than detector efficiency.

How do you see spectroscopy vs. spectrometry? In this context, what does ANGLE address and what doesn't it?
In the ANGLE context, gamma-spectroscopy is a qualitative analysis, a means of determining which radionuclides are present in the sample.

Gamma-spectrometry is quantitative analysis, it means determining the quantity/concentration/activity of radionuclides present in the sample Gamma-spectrometry can, thus, be regarded as the quantification of spectroscopic results. Logically, spectroscopy precedes spectrometry, but eventually spectroscopy without spectrometry does not make much sense.

APPENDIX B. COMMAND LINE PARAMETERS

The new XML-based file format, used in all files created by ANGLE, allows easy integration with third-party applications (e.g., in-house developed software).

To enable flexible control from other application or batch files, ANGLE 5 supports a set of command line parameters. As an example, third-party application can create or change input file(s), run ANGLE, and then obtain the results from the resulting file(s). A very efficient demonstration of this method was used to generate and run nearly 10,000 files in a study on accounting for detector crystal edge rounding (bulletization) in gamma-efficiency calculations (Literature [3]).

The command line syntax for ANGLE 5 is (square brackets indicate that parameters are optional):

```
ANGLE [file_name] [/source:file_list] [/output:folder_name] [/samefolder]
      [/json] [/yaml] [/close] [/shutdown] [/help]
```

B.1 SPECIFYING CALCULATION PARAMETERS FILES

To specify one or more calculation parameters files, you can simply pass their names, and ANGLE will run calculations for each of them. For example, if you run:

```
ANGLE params.savx
```

ANGLE will automatically start calculations based on the file "`params.savx`". The name of the file with results will be the same, except the extension will be ".outx" ("`params.outx`", in this case).

To be able to run ANGLE from command line you will need to either:

1. Go to the folder in which ANGLE is installed and run it from there,
2. Specify the full path to the ANGLE executable file, or
3. Add the ANGLE installation path to the PATH environment variable.

It is possible to specify more than one file, each as a separate parameter, for example:

```
ANGLE params1.savx params2.savx
```

You may omit the ".savx" extension, so the equivalent of the previous example would be:

```
ANGLE params1 params2
```

If the path is not specified, as in the examples above, ANGLE will assume the file is in the default folder for calculation parameter files (see "**Configuration**"). If calculation parameter files are located in other folder(s), you will need to specify the full path, for example:

```
ANGLE C:\parameters\params.savx
```

Please note that, if a file or path names contain spaces, you need to enclose them with quotation marks, for example:

```
ANGLE "C:\parameter files\file 2.savx"
```

B.2 SPECIFYING THE LIST OF CALCULATION PARAMETERS FILES

If you would like to run calculations for many calculation parameters files at once, it would not be possible to pass all the file names as parameters, due to the limitation on the maximal command line length. To be able to do this, you can create a text file containing all file names and pass it using the "`/source`" parameter. For example:

```
ANGLE /source:C:\temp\file_list.txt
```

Each calculation parameters file name should be defined in a separate line. You should not enclose them with quotation marks, even when they contain space characters.

ANGLE assumes UTF-8 encoding for all files, so if you want to specify file and path names with non-English characters, please select the UTF-8 encoding in your application.

B.3 SPECIFYING THE OUTPUT FOLDER

By default, ANGLE saves calculation results files to their default folder (see "**Configuration**"). If you want to specify another folder, you can do it using the "`/output`" parameter. For example:

```
ANGLE /source:C:\temp\file_list.txt /output:C:\results
```

If you prefer to have the calculation results files in the same folder as the original calculation parameters files, you can use the "`/samefolder`" parameter. In the following example, ANGLE will run calculations for all files specified in the file "`C:\temp\file_list.txt`" and put each resulting file in the same folder as the matching source one:

```
ANGLE /source:C:\temp\file_list.txt /samefolder
```

B.4 SPECIFYING THE OUTPUT FORMAT

By default, ANGLE saves calculation results files in XML files with the ".outx" extension. If you want to save the results also in JSON and/or YAML format, you can use the "`/json`" and/or "`/yaml`" parameters:

```
ANGLE /source:C:\temp\file_list.txt /json
```

JSON and YAML files will be created in the same folder as the calculation results files and will have the same name.

B.5 SPECIFYING THE END ACTION

Using command line parameters, you can specify if you would like to automatically close ANGLE, or even to shut down Windows, when calculations finish.

To automatically close ANGLE when the last calculation parameter file is processed, use the "`/close`" parameter, for example:

```
ANGLE /source:C:\temp\file_list.txt /close
```

When you are running numerous files at once, calculations may last for several hours. In this case you may want to use "`/shutdown`" parameter to automatically shut down Windows when the calculations are finished:

```
ANGLE /source:C:\temp\file_list.txt /shutdown
```

When you use one of these parameters, the calculation results window will not be displayed at the end.

B.6 HELP ON COMMAND LINE PARAMETERS

To get help on ANGLE command line parameters, simply run ANGLE with the "`/help`" parameter specified:

```
ANGLE /help
```

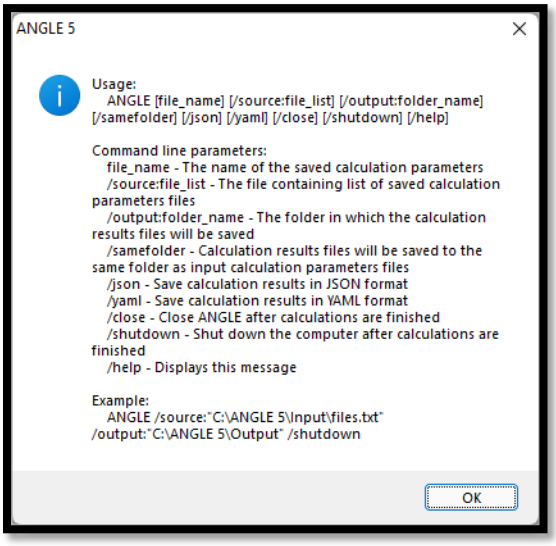

Figure 77. Command Line Parameters Help

THIS PAGE INTENTIONALLY LEFT BLANK.

APPENDIX C. FILE FORMATS

ANGLE 5 utilizes a completely new format for all file types. Instead of a proprietary binary format, now all ANGLE files are text files based on the XML syntax (*Extensible Markup Language*), which is both human- and machine-readable. Thus, all ANGLE files can now be easily used from third-party applications, such as in-house and *ad hoc* built software, as well as spreadsheet and word processing software.

Being simple text files, they are also human-readable, so you can use a text editor to view or edit them.

Although ANGLE files can be opened with spreadsheet or word processing software, it is not recommended to use them for modifications. Please use text editors, instead.

ANGLE 5 is a multi-language application, and it uses the *Unicode* standard to be able to display and use all international characters. All files created by ANGLE are **UTF-8 encoded**, which is the most common encoding used today. If you want to use non-English characters, please be sure to use UTF-8 encoding in your text editor or application.

The first 128 characters in UTF-8 standard are the same as in 7-bit ASCII. This means that you can use any text editor, even those not supporting UTF-8 encoding, as long as you use only English letters.

C.1 ANGLE FILE STRUCTURE

The structure and naming in ANGLE files are pretty straightforward, so one can read and understand them without much effort. Here, we will explain the structure of all the file types in ANGLE.

To keep it as simple as possible, here we will not use any *XML Schemas* to describe the formats of XML documents, but plain words.

In our examples we will use blue letters to distinguish *XML elements*, *attribute* names will be displayed in red letters, and their *values* in purple. *Comments* will be displayed in *green* letters. Mandatory elements and attributes will be in **bold**.

XML is **case sensitive**, so be sure to use exact tag and attribute names as specified. This is also important for predefined values, such as detector types.

All attribute values must be enclosed with quotes. Different types of values are indicated by the following abbreviations (in *italics*):

- *str* – Non-empty string (text).
- *str0* – String, which can be empty (i.e., zero-length).
- *float* – Positive real number.
- *float0* – Non-negative real number.
- *int* – Positive integer number.

- *bool* – Logical value: only "yes" or "no".

Decimal separator for real numbers is a point (". "), regardless of the settings on your computer.

ANGLE displays numbers according to your system settings. But, regardless of your settings, all files use the point character as a decimal separator, to maintain the compatibility among different computers and users.

The first line in every ANGLE file is the same and it defines the XML standard and encoding used, followed by a single "angle" element, which encloses the rest of the document:

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="5.0" build="5.0.0.274" units="mm">
  ...
</angle>
```

The element "angle" must have three attributes specified:

- **generator**: Must have the value of **"ANGLE"**.
- **version**: Minimum version of ANGLE required to open the file.
- **build**: Version of ANGLE which created the file.
- **units**: Units of length used in the file. Allowed values are: "mm" (millimeters), "cm" (centimeters) and "in" (inches).

C.2 ENERGIES DATA SPECIFICATION

Energies files (with ".engx" extension) have the simplest structure. They contain a set of "**energy**" elements, one for each gamma-energy of interest, enclosed by a single "**energies**" element:

```
<energies name=str>
  <energy>float</energy>
  ...
  <energy>float</energy>
</energies>
```

C.2.1 Example

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="4.0" build="5.0.0.274" units="mm">
  <energies name="Mixed Gamma">
    <energy>59.5</energy>
    <energy>88</energy>
    <energy>122.1</energy>
    <energy>165.9</energy>
    <energy>279.2</energy>
    <energy>391.7</energy>
    <energy>661.7</energy>
    <energy>898</energy>
    <energy>1173.2</energy>
    <energy>1332.5</energy>
    <energy>1836.1</energy>
  </energies>
</angle>
```

C.3 MATERIAL DATA SPECIFICATION

The structure of material files (".matx" extension) differs depending on in which form the material was specified.

In case when the material is specified as the **mixture of elements**, the material files contain a set of "**element**" elements (one for each element used in the material), enclosed by a single "**elements**" element, inside the single "**material**" element:

```
<material name=str density=float>
  <elements>
    <element symbol=str massFraction=float />
    ...
    <element symbol=str massFraction=float />
  </elements>
</material>
```

Attribute "**density**" should have the value of the material density in g/cm^3.

Attribute "**massFraction**" represents the mass fraction for the element defined with the "**symbol**" attribute (in percentages). The sum of all specified mass fractions must be equal to 100.

C.3.1 Example 1

This example illustrates the specification of a material named "**Polypropylene**" with a density of **0.855 g/cm^3**. It consists of two elements: **Carbon** (symbol "**C**", mass share **85.629%**) and **Hydrogen** (symbol "**H**", mass share **14.371%**).

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="4.0" build="5.0.0.274" units="mm">
  <material name="Polypropylene" density="0.855">
    <elements>
      <element symbol="C" massFraction="85.629" />
      <element symbol="H" massFraction="14.371" />
    </elements>
  </material>
</angle>
```

When material is specified as the **compound**, the material files also contain a set of "**element**" elements (one for each element used in the material), enclosed by a single "**compound**" element, inside the single "**material**" element:

```
<material name=str density=float>
  <compound chemicalFormula=str>
    <element symbol=str atoms=int />
    ...
    <element symbol=str atoms=int />
  </compound>
</material>
```

Attribute "**density**" should have the value of the material density in g/cm^3.
Attribute "**chemicalFormula**" is optional and it contains the chemical formula.
Attribute "**atoms**" represents the number of atoms of the element defined with the "**symbol**" attribute.

C.3.2 Example 2

This example illustrates the specification of a material named "**Calcium carbonate**" with a density of **2.71 g/cm^3**, whose chemical formula is **$CaCO_3$**.

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="5.0" build="5.0.0.274" units="mm">
  <material name="Calcium carbonate" density="2.71">
    <compound chemicalFormula="CaCO3">
      <element symbol="Ca" atoms="1" />
      <element symbol="C" atoms="1" />
      <element symbol="O" atoms="3" />
    </compound>
  </material>
</angle>
```

Finally, if the material is specified as the **mixture of compounds**, the material files will contain a set of "**compounds**" elements, enclosed by a single "**compound**":

```
<material name=str density=float>
  <compounds>
    <compound massFraction=float chemicalFormula=str>
      <element symbol=str atoms=int />
      ...
      <element symbol=str atoms=int />
    </compound>
    ...
  </compounds>
</material>
```

Attribute "**massFraction**" represents the mass fraction of each compound (in percentages). The sum of all specified mass fractions must be equal to 100.

C.3.3 Example 3

This example illustrates the specification of a 4% mixture of salt (**sodium chloride**) dissolved in **water**.

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="5.0" build="5.0.0.274" units="mm">
  <material name="4% NaCl" density="1.047">
    <compounds>
      <compound massFraction=”96" chemicalFormula="H2O">
        <element symbol="H" atoms="2" />
        <element symbol="O" atoms="1" />
      </compound>
      <compound massFraction=”4" chemicalFormula="NaCl">
        <element symbol="Na" atoms="1" />
        <element symbol="Cl" atoms="1" />
      </compound>
    </compounds>
  </material>
</angle>
```

C.3.4 Predefined Materials

ANGLE comes with a set of 19 predefined materials:

- **Air**
- **Aluminium**
- **Aluminium oxide**

- **Beryllium**
- **Brass**
- **Calcium carbonate**
- **Carbon fiber**
- **Copper**
- **Germanium**
- **Glass**
- **Gold**
- **Magnesium**
- **Magnesium oxide**
- **Mylar/PET**
- **NaI**
- **Nickel**
- **Plastic**
- **Silicone**
- **Water**

You can select any of these materials simply by specifying only their name, as in this example:

```
<material name="Water" />
```

Since XML is **case sensitive**, you need to specify the name of a built-in material name exactly as given. For example, “Water” will be interpreted correctly, but “water” or “WATER” will not.

C.4 NUCLIDE SET SPECIFICATION

Sets of nuclides of interest are saved in files with the “.nucx” extension. They contain a set of “**nuclide**” elements (one for each nuclide in the set), enclosed by a single “**nuclides**” element:

```
<nuclides name=str>
  <nuclide>str</nuclide>
  ...
</source>
```

The “**nuclides**” element has one attribute “**name**” containing the name of the set of nuclides. Each of “**nuclide**” elements contain the name of the nuclide as the value.

C.4.1 Example

```
<nuclides name="Eu">
  <nuclide>Eu-152</nuclide>
  <nuclide>Eu-154</nuclide>
  <nuclide>Eu-155</nuclide>
  <nuclide>Eu-156</nuclide>
</source>
```

C.5 SOURCE DATA SPECIFICATION

ANGLE does not store parameters of the radioactive source in dedicated files (as energies and materials), but it includes source data as a part of the reference efficiency curve, calculation parameters and calculation results data.

Source parameters consist of two attributes, "**radius**" and "**height**" and the specification of the source material:

```
<source radius=float0 height=float0>
  <material Source material specification />
</source>
```

Material is specified as in the way defined previously, in the "Material data" section. If the source height is equal to zero (i.e., in case of "disk" or "point sources") a material does not need to be specified.

C.5.1 Example

```
<source radius="74.76" height="49.3">
  <material name="Water" />
</source>
```

C.6 CONTAINER DATA SPECIFICATION

ANGLE stores the exported container data to files with a ".conx" extension. The structure of container data is:

```
<container type=str name=str description=str0>

  <shape innerRadius=float sideThickness=float0
         botomThickness=float footHeight=float0
         cavityRadius=float cavityDepth=float sideInnerThickness=float0
         bottomUpperThickness=float bottomLowerThickness=float />

  <material Container material specification />

  <coatings>
    <coating sideThickness=float0 bottomThickness=float0
             bottomUpperThickness=float0 bottomLowerThickness=float0>
      <material Coating material specification />
    </coating>
    ...
  </coatings>

</container>
```

A container type can have one of two predefined values:

- **Cylindrical**
- **Marinelli**

Container dimensions are defined by the attributes of the mandatory element "**shape**". Attributes depend on the container type defined. For a cylindrical container, the attributes of the "**shape**" element (and their types) are:

- **innerRadius** (***float***)

- sideThickness (*float0*)
- botomThickness (*float0*)
- footHeight (*float*)

For a Marinelli container, the attributes of the "**shape**" element are:

- **innerRadius** (***float***)
- cavityRadius (*float*)
- cavityDepth (*float*)
- sideInnerThickness (*float0*)
- bottomUpperThickness (*float*)
- bottomLowerThickness (*float*)

Container material is specified by the mandatory element "**material**" (see "Material data specification").

If you want to specify coating layers for the container, you have to add the element "**coatings**" with up to two "**coating**" elements, one for each layer. The attributes of the "**coating**" element (and their types) for cylindrical container are:

- **sideThickness** (***float0***)
- bottomThickness (*float0*)

The attributes of the "**coating**" element (and their types) for Marinelli container are:

- **sideThickness** (***float0***)
- bottomUpperThickness (*float0*)
- bottomLowerThickness (*float0*)

Each thickness attribute for a coating layer can be zero (*float0*), but not all of them at the same time. A coating layer material must be defined inside each "**coating**" element.

C.6.1 Example

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="4.0" build="5.0.0.274" units="mm">
  <container type="Cylindrical" name="Coated cylinder"
             description="Cylindrical container with two coating layers">
    <shape innerRadius="160" sideThickness="2.5"
           bottomThickness="3" footHeight="0" />
    <material name="Aluminium" />
    <coatings>
      <coating sideThickness="1E-3" bottomThickness="1E-3">
        <material name="Mylar/PET" />
      </coating>
      <coating sideThickness="0.12" bottomThickness="0.1">
        <material name="Plastic" />
      </coating>
    </coatings>
  </container>
</angle>
```

C.7 GEOMETRY DATA SPECIFICATION

ANGLE stores the exported geometry data to files with a ".geox" extension. The structure of geometry data is:

```
<geometry type=str name=str description=str0>

  <holder outerRadius=float height=float0>
    <cap thickness=float0>
      <material Holder cap material specification />
    </cap>
    <wall thickness=float0>
      <material Holder wall material specification />
    </wall>
  </holder>

  <absorbingLayers>
    <absorbingLayer topThickness=float0 bottomThickness=float0
                    sideThickness=float0>
      <material Absorbing layer material specification />
    </absorbingLayer>
    ...
  </absorbingLayers>

</geometry>
```

Geometry type can be one of three predefined values:

- **General**
- **Marinelli**
- **Well**

If the geometry you are specifying is for a well detector or Marinelli container, you have to specify "**Well**" or "**Marinelli**" for its type, respectively. Otherwise, use the "**General**" type.

If you specify the general type of geometry, you have to define the holder parameters. To do this, use the element "holder". With two attributes of this element, you can define the holder's **outer radius** and its **height**.

Inside the "holder" element, you have to specify two sub-elements: "**cap**" and "**wall**" – for holder cap and wall parameters. They both have one attribute: "**thickness**". If the thickness is greater than zero, you will also have to specify the material.

If there are additional absorbing layers, you can define them inside the "absorbingLayers" element with up to five "**absorbingLayer**" sub-elements, one for each.

Attributes of the "**absorbingLayer**" elements (and their types) for cylindrical containers are:

- **topThickness** (*float0*)
- bottomThickness (*float0*)
- **sideThickness** (*float0*)

The attribute "bottomThickness" is used only for the geometry for well detectors.

Each thickness attribute can be zero (*float0*), but not all of them at the same time.

Absorbing layer material specification must be defined inside each "**absorbingLayer**" element.

C.7.1 Example

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="4.0" build="5.0.0.274" units="mm">
  <geometry type="General" name="Plastic rings"
            description="Plastic rings below the container">
    <holder outerRadius="40" height="127">
      <cap thickness="3">
        <material name="Plastic" />
      </cap>
      <wall thickness="10">
        <material name="Plastic" />
      </wall>
    </holder>
    <absorbingLayers>
      <absorbingLayer topThickness="0.17" sideThickness="0.17">
        <material name="Silicone" />
      </absorbingLayer>
    </absorbingLayers>
  </geometry>
</angle>
```

C.8 DETECTOR DATA SPECIFICATION

The structure of detector data (".detx" extension) is more complex and depends on the detector type:

```
<detector type=str name=str description=str0>

    <crystal height=float radius=float bulletizingRadius[1,2,3,4]=float0 />

    <core height[1,3]=float radius=float rounded[1,3]=bool />[1,2,3,4]

    <well depth=float radius=float />[6,8]

    <inactiveGe topThickness[1,2,3,4,5]=float0 sideThickness[1,2,3,4,5]=float0
                topUpperThickness[6]=float0 topLowerThickness[6]=float0
                sideInnerThickness[6]=float0 sideOuterThickness[6]=float0
                bottomThickness[5]=float0 />[1,2,3,4,5,6]

    <reflectingLayer topThickness[7]=float0 sideThickness[7]=float0
                     topUpperThickness[8]=float0 topLowerThickness[8]=float0
                     sideInnerThickness[8]=float0 sideOuterThickness[8]=float0>[7,8]
        <material Reflecting layer material specification />
    </reflectingLayer>

    <contact topThickness[1]=float0 sideThickness=float0>[1,2]
        <material Contact material specification />
    </contact>

    <contactPin radius=float0>[1,2,3,4,5]
        <material Contact pin material specification />
    </contactPin>

    <opticalCoupling thickness=float0>[7]
        <material Optical coupling material specification />
    </opticalCoupling>

    <photomultiplierTube>[7]
      <wall thickness=float0>
        <material Photomultiplier tube wall material specification />
      </wall>
      <window thickness=float0>
        <material Photomultiplier tube window material specification />
      <window>
```

```
    </photomultiplierTube>

    <endCap topThickness[1,2,3,4,5,7]=float sideThickness=float
            topUpperThickness[6,8]=float topLowerThickness[6,8]=float >
        <material End-cap material specification />
        <window thickness=float radius=float
                holeRadius=float holderThickness=float0>[1,2,3,4,5,7]
          <material End-cap window material specification />
        </window>
      <coatings>
        <coating topThickness[1,2,3,4,5,7]=float sideThickness=float
                 topUpperThickness[6,8]=float topLowerThickness[6,8]=float >
          <material End-cap coanting material specification />
        </coating>
        ...
      </coatings>
    </endCap>

    <antimicrophonicShield topThickness[1,2,3,4,5,7]=float sideThickness=float
                           topUpperThickness[6,8]=float topLowerThickness[6,8]=float >
          <material Antimicrophonic shield material specification />
    </antimicrophonicShield>

    <vacuum topThickness[1,2,3,4,5,7]=float0 bottomThickness[A1,2,3,4,5,7]=float0
            sideThickness[N]=float0 sideOuterThickness[A]=float0
            sideInnerThickness[A]=float0 topUpperThickness[6,8]=float0
            bottomUpperThickness[A6,8]=float0 topLowerThickness[6,8]=float0
            bottomLowerThickness[A6,8]=float0 />

    <housing>[1,2,3,4,5,7]
        <sideInner thickness=float0>
          <material Inner side housing material specification />
        </sideInner>
        <sideOuter thickness=float0>
          <material Outer side housing material specification />
        </sideOuter>
        <topLower thickness=float0>
          <material Lower top housing material specification />
        </topLower>
        <topUpper thickness=float0>
          <material Upper top housing material specification />
        </topUpper>
    </housing>

  </detector>
```

The detector type can have one of eight predefined values:

1. **Closed-end coaxial HPGe**
2. **True coaxial HPGe**
3. **Closed-end coaxial Ge(Li)**
4. **Open-end coaxial Ge(Li)**
5. **Planar LEPD**
6. **Well**
7. **NaI**
8. **NaI Well**

Many detector parameters depend on their type. Therefore, we will use the numbers from the above (displayed in superscript) to indicate the availability of a certain element or attribute. For example, the line:

<core height[1,3]=*float* radius=*float* rounded[1,3]=*bool* />[1,2,3,4]

ends with "[1,2,3,4]", meaning that the "**core**" element can be used only with detector types 1, 2, 3 and 4, or *Closed-end coaxial HPGe*, *True coaxial HPGe*, *Closed-end coaxial Ge(Li)* and *Open-end coaxial Ge(Li)*. But, out of those four, only attributes "`height`" and "`rounded`" can be used with detector types 1 and 3.

Detector crystal parameters are defined by "**height**", "**radius**" and "**bulletizingRadius**" attributes (the last one only for the first four detector types).

A detector crystal core (which exists in detectors 1, 2, 3 and 4) is specified using the "**core**" element with three attributes: "**height**", "**radius**" and "**rounded**". Since detectors 2 and 4 are true coaxial, only a radius attribute is relevant for these.

The well detectors' cavity size (both Germanium and NaI) is defined with two parameters of the "**well**" element: "**depth**" and "**radius**".

Germanium detectors' dead layer is specified by the "**inactiveGe**" element. There are two attributes for HPGe and Ge(Li) detectors: "**topThickness**" and "**sideThickness**". For planar detectors, also the third parameter "**bottomThickness**" has to be specified. The attributes for well detectors are: "**topUpperThickness**" "**topLowerThickness**", "**sideInnerThickness**" and "**sideOuterThickness**".

Reflecting layer for NaI detectors is specified by the "**reflectingLayer**" element. The attributes of this element for common (cylindrical) detector crystal are "**topThickness**" and "**sideThickness**", while there are four of them for the well NaI detector: "**topUpperThickness**" "**topLowerThickness**", "**sideInnerThickness**" and "**sideOuterThickness**". Reflecting layer material has to be specified using the "material" sub-element (except when all specified attributes are equal to zero).

Contact thicknesses and material for HPGe detectors are specified using the element "**contact**" and its attributes "**sideThickness**" and "**topThickness**" (in cases of closed-end coaxial HPGe detector with a flat core) and the sub-element "material" (except when both specified attributes are equal to zero).
The contact pin is defined using the "**contactPin**" element and its "**radius**" attribute, and the "material" sub-element (if the radius specified is greater than zero).

The optical coupling for NaI detectors has to be defined by the "**opticalCoupling**" element and its attribute "**thickness**". If the thickness is greater than zero, then the material of the optical coupling must be defined using the "material" sub-element.

A photomultiplier tube, utilized in NaI detectors, is defined by the "**photomultiplierTube**" element. The wall and window of the tube are, further, defined by the "**wall**" and "**window**" sub-elements. Both have one attribute named "**thickness**" and "material" sub-element (if the thickness specified is greater than zero).

The detector end-cap for all detector types is defined by the mandatory "**endCap**" element: thicknesses using the attributes "**sideThickness**" for all types, "**topThickness**" for all non-well types and "**topUpperThickness**" and "**topLowerThickness**" for well-type detectors, as well as with the "**material**" sub-element.

The end-cap window, if present on the end-cap, can be defined by four attributes of the "window" sub-element of the "**endCap**" element: "**thickness**", "**radius**", "holeRadius" and "holderThickness" (the first two are mandatory) and the "**material**" sub-element.

Finally, if the end-cap is coated, you can define its coating layers using the "coatings" sub-element of the "**endCap**" element. Up to two layers can be defined using the "**coating**" sub-elements for each, with the attributes "**sideThickness**" for all detector types, "**topThickness**" for all non-well types and "**topUpperThickness**" and "**topLowerThickness**" for well-type detectors. Any of these attributes (but not all of them) can have the value of zero. Every coating layer material is defined using the "**material**" sub-element.

You can define the antimicrophonic shield using the optional element "antimicrophonicShield" with four attributes: "**sideThickness**" for all detector types, "**topThickness**" for all non-well types and "**topUpperThickness**" and "**topLowerThickness**", and the "**material**" sub-element.

The number of parameters which define the vacuum inside the detector varies depending on the detector type and the antimicrophonic shield. The attributes of the "**vacuum**" element which are present in cases when an antimicrophonic shield exists are indicated with the letter "A" in the superscript. The attribute "**sideThickness**" must be defined for every detector type if an antimicrophonic shield is not present (indicated with the letter "N" in the superscript).

The last parameter for non-well detectors is detector housing. It is specified using the "**housing**" element. Two horizontal and vertical layers are defined by four sub-elements: "**sideInner**", "**sideOuter**", "**topLower**" and "**topUpper**", each of them having only one attribute: "**thickness**". All elements are mandatory, but thicknesses can be equal to zero. For each layer with non-zero thickness, the material must be defined using the "material" sub-element.

C.8.1 Example

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="4.0" build="5.0.0.274" units="mm">
  <detector type="Closed-end coaxial HPGe" name="43-TN21827A"
            description="In Clamshell">
    <crystal height="63.8" radius="31.5" bulletizingRadius="8" />
    <core height="42.6" radius="4.55" rounded="yes" />
    <inactiveGe topThickness="0.0003" sideThickness="0.0003" />
    <contact sideThickness="0.7">
      <material name="Germanium" />
    </contact>
    <contactPin radius="2">
      <material name="Brass" density="8.41">
        <elements>
          <element symbol="Cu" massFraction="60" />
          <element symbol="Zn" massFraction="39.25" />
          <element symbol="Sn" massFraction="0.75" />
        </elements>
      </material>
    </contactPin>
    <endCap topThickness="1" sideThickness="1">
      <material name="Aluminium" />
      <window thickness="0.5" radius="40" holeRadius="40" holderThickness="0">
        <material name="Beryllium" />
      </window>
    </endCap>
    <vacuum topThickness="7" sideThickness="8.24" />
    <housing>
      <sideInner thickness="0.76">
        <material name="Aluminium" />
      </sideInner>
      <sideOuter thickness="0" />
      <topLower thickness="1E-9">
        <material name="Aluminized Mylar" density="2.035">
          <elements>
            <element symbol="C" massFraction="31.25" />
            <element symbol="H" massFraction="2.1" />
```

```
            <element symbol="O" massFraction="16.65" />
            <element symbol="Al" massFraction="50" />
          </elements>
        </material>
      </topLower>
      <topUpper thickness="0" />
    </housing>
  </detector>
</angle>
```

C.9 REFERENCE EFFICIENCY CURVE DATA SPECIFICATION

Files with reference efficiency curve data have a ".recx" extension. The structure of REC data is:

```
<referenceEfficiencyCurve name=str description=str0>

  <experimentalPoints>
    <point energy=float efficiency=float />
      ...
  </experimentalPoints>

  <regions>
    <region start=float end=float polynomOrder=float />
    ...
  </regions>

  <detector name=str />

  <container Reference container specification />

  <geometry Reference geometry specification />

  <source Reference source specification />

</referenceEfficiencyCurve>
```

REC parameters contain values for experimental points, interpolation, the detector name, and a container, geometry and the source used for the reference measurement.

Experimental points, i.e., the results of the reference measurement, are defined inside the "**experimentalPoints**" element. Each energy-efficiency pair is represented by one "**point**" sub-element with two attributes: "**energy**" and "**efficiency**".

Reference efficiency curve interpolation is specified inside the "regions" element (if the curve is interpolated, not discrete). Each region is defined by one "**region**" element and its attributes "start", "**end**" and "**polynomOrder**" which define the boundary energies of the region and the polynomial order. The "start" attribute is mandatory for the first region, but it is not used in any subsequent region, since the end of one region is automatically assumed to be the start of the next one.

ANGLE will calculate polynomial coefficients and insert them in form of a comment for each region.

The name of the detector used for reference measurements is specified by the "**name**" attribute of the "**detector**" element.

The rest of the REC data are parameters for the reference container and geometry (if any) and the radioactive source used, the structure of which was specified earlier (see "Container data specification", "Geometry data specification" and "Source data specification").

C.9.1 Example

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="4.0" build="5.0.0.274" units="mm">
  <referenceEfficiencyCurve name="Eff_curve" description="20 mL LSC vial">
    <experimentalPoints>
      <point energy="99.45" efficiency="0.006404" />
      <point energy="129.02" efficiency="0.006427" />
      <point energy="277.29" efficiency="0.004213" />
      <point energy="338.22" efficiency="0.003766" />
      <point energy="510.52" efficiency="0.003055" />
      <point energy="583.03" efficiency="0.002497" />
      <point energy="755.27" efficiency="0.002089" />
      <point energy="772.33" efficiency="0.002063" />
      <point energy="835.41" efficiency="0.002043" />
      <point energy="964.79" efficiency="0.001715" />
      <point energy="968.96" efficiency="0.001654" />
    </experimentalPoints>
    <regions>
      <region start="70" end="130" polynomOrder="2" />
      <region end="1200" polynomOrder="2" />
    </regions>
    <detector name="43-TN21827A" />
    <container type="Cylindrical" name="20 mL plastic vial" description="">
      <shape innerRadius="26" sideThickness="1"
             bottomThickness="1" footHeight="0" />
      <material name="Plastic" />
    </container>
    <geometry type="General" name="Plastic rings"
              description="Plastic rings below the container ">
      <holder outerRadius="10" height="20">
        <cap thickness="0" />
        <wall thickness="10">
          <material name="Plastic" />
        </wall>
      </holder>
    </geometry>
    <source radius="13" height="10">
      <material name="Water" />
    </source>
  </referenceEfficiencyCurve>
</angle>
```

C.10 CALCULATION PARAMETERS DATA SPECIFICATION

Calculation parameters files contain all the parameters needed for calculation: parameters for the detector used, container, geometry, etc. The extension of the calculation parameters files is ".savx". The structure of the calculation parameters files is as follows:

```
<detector Detector specification />

<container Container specification />

<geometry Geometry specification />

<source Source specification />

<energies Energies specification />

<precision>float</precision>

<referenceEfficiencyCurve REC specification />
```

All structures in the specification above have been defined previously, except for the "**precision**" element, which contains single real value representing the calculation precision (in percentages).

The container, geometry and REC elements are optional (and absent in case when no container/geometry/reference efficiency curve is to be used).

C.10.1 Example

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="4.0" build="5.0.0.274" units="mm">
  <detector type="Closed-end coaxial HPGe" name="43-TN21827A"
            description="In Clamshell">
    <crystal height="63.8" radius="31.5" bulletizingRadius="8" />
    <core height="42.6" radius="4.55" rounded="yes" />
    <inactiveGe topThickness="0.0003" sideThickness="0.0003" />
    <contact sideThickness="0.7">
      <material name="Germanium" />
    </contact>
    <contactPin radius="2">
      <material name="Brass" density="8.41">
        <elements>
          <element symbol="Cu" massFraction="60" />
          <element symbol="Zn" massFraction="39.25" />
          <element symbol="Sn" massFraction="0.75" />
        </elements>
      </material>
    </contactPin>
    <endCap topThickness="1" sideThickness="1">
      <material name="Aluminium" />
      <window thickness="0.5" radius="40" holeRadius="40" holderThickness="0">
        <material name="Beryllium" />
      </window>
    </endCap>
    <vacuum topThickness="7" sideThickness="8.24" />
    <housing>
      <sideInner thickness="0.76">
        <material name="Aluminium" />
      </sideInner>
      <sideOuter thickness="0" />
      <topLower thickness="1E-9">
        <material name="Aluminized Mylar" density="2.035">
          <elements>
            <element symbol="C" massFraction="31.25" />
            <element symbol="H" massFraction="2.1" />
            <element symbol="O" massFraction="16.65" />
            <element symbol="Al" massFraction="50" />
          </elements>
        </material>
      </topLower>
      <topUpper thickness="0" />
    </housing>
  </detector>
  <source radius="6.2" height="7.3">
    <material name="Calcium carbonate" />
  </source>
  <energies name="Mixed Gamma">
    <energy>59.5</energy>
    <energy>88</energy>
    <energy>122.1</energy>
    <energy>165.9</energy>
    <energy>279.2</energy>
    <energy>391.7</energy>
    <energy>661.7</energy>
    <energy>898</energy>
    <energy>1173.2</energy>
    <energy>1332.5</energy>
    <energy>1836.1</energy>
  </energies>
  <precision>1</precision>
</angle>
```

C.11 CALCULATION RESULTS DATA SPECIFICATION

Calculation results files (".outx" extension) contain all the parameters from the calculation parameters files plus the result values and calculation time:

```
<detector Detector specification />

<container Container specification />

<geometry Geometry specification />

<source Source specification />

<energies Energies specification />

<precision>float</precision>

<referenceEfficiencyCurve REC specification />

<results>
  <result energy=float solidAngle=float solidAnglePrecision=float efficiency=float
efficiencyPrecision=float />
  ...
</results>

<cascadeSummingCorrections>
  <nuclide name=str>
    <correction energy=float value=float branchingRatio=float
correctedBranchingRatio=float />
    ...
  </nuclide >
  ...
</cascadeSummingCorrections>

<elapsedTime>float</elapsedTime>
```

In addition to the calculation parameters structure, the results file contains the "**results**" element, which holds the actual results, "**cascadeSummingCorrections**" element, containing the true coincidence summing correction values and "**elapsedTime**" element, containing the calculation time in seconds.

The calculated result for each energy is represented with one "**result**" sub-element of the element "**results**". It contains three mandatory attributes: "**energy**", "**solidAngle**" and "**solidAnglePrecision**" and two optional ones: "efficiency" and "efficiencyPrecision". Efficiency attributes will contain the detector efficiency for the given energy and the achieved estimated precision (in percentages). If the reference efficiency curve is not specified, efficiency attributes will be omitted from the output file.

True coincidence summing corrections for each nuclide is represented with one "**nuclide**" sub-element of the "**cascadeSummingCorrections**" element, with the nuclide name as the only attribute. Each of "**nuclide**" elements contains one or more "**correction**" elements, one for each relevant energy, with four real attributes: "**energy**", "**value**", "**branchingRatio**" and "**correctedBranchingRatio**".

C.11.1 Example

```
<?xml version="1.0" encoding="utf-8"?>
<angle generator="ANGLE" version="4.0" build="5.0.0.274" units="mm">
  <detector type="Closed-end coaxial HPGe" name="43-TN21827A"
            description="In Clamshell">
    <crystal height="63.8" radius="31.5" bulletizingRadius="8" />
    <core height="42.6" radius="4.55" rounded="yes" />
    <inactiveGe topThickness="0.0003" sideThickness="0.0003" />
```

```
    <contact sideThickness="0.7">
      <material name="Germanium" />
    </contact>
    <contactPin radius="2">
      <material name="Brass" density="8.41">
        <elements>
          <element symbol="Cu" massFraction="60" />
          <element symbol="Zn" massFraction="39.25" />
          <element symbol="Sn" massFraction="0.75" />
        </elements>
      </material>
    </contactPin>
    <endCap topThickness="1" sideThickness="1">
      <material name="Aluminium" />
      <window thickness="0.5" radius="40" holeRadius="40" holderThickness="0">
        <material name="Beryllium" />
      </window>
    </endCap>
    <vacuum topThickness="7" sideThickness="8.24" />
    <housing>
      <sideInner thickness="0.76">
        <material name="Aluminium" />
      </sideInner>
      <sideOuter thickness="0" />
      <topLower thickness="1E-9">
        <material name="Aluminized Mylar" density="2.035">
          <elements>
            <element symbol="C" massFraction="31.25" />
            <element symbol="H" massFraction="2.1" />
            <element symbol="O" massFraction="16.65" />
            <element symbol="Al" massFraction="50" />
          </elements>
        </material>
      </topLower>
      <topUpper thickness="0" />
    </housing>
  </detector>
  <source radius="6.2" height="7.3">
    <material name="Calcium carbonate" />
  </source>
  <energies name="Mixed Gamma">
    <energy>59.5</energy>
    <energy>88</energy>
    <energy>122.1</energy>
    <energy>165.9</energy>
    <energy>279.2</energy>
    <energy>391.7</energy>
    <energy>661.7</energy>
    <energy>898</energy>
    <energy>1173.2</energy>
    <energy>1332.5</energy>
    <energy>1836.1</energy>
  </energies>
  <precision>35</precision>
  <results>
    <result energy="59.5" solidAngle="2.50378218272655" />
    <result energy="88" solidAngle="2.83597906334898" />
    <result energy="122.1" solidAngle="2.87159904601627" />
    <result energy="165.9" solidAngle="2.74870442559007" />
    <result energy="279.2" solidAngle="2.46701808595213" />
    <result energy="391.7" solidAngle="2.31172003060593" />
    <result energy="661.7" solidAngle="2.10378183392979" />
    <result energy="898" solidAngle="1.97445406904723" />
    <result energy="1173.2" solidAngle="1.85295812084583" />
    <result energy="1332.5" solidAngle="1.79452898448704" />
    <result energy="1836.1" solidAngle="1.65669996398461" />
  </results>
  <cascadeSummingCorrections>
    <nuclide name="Ac-228">
```

```
        <correction energy="18.415" value="0.89394755817195" branchingRatio="0.00014"
 correctedBranchingRatio="0.000125152658144073" />
        ...
      </nuclide>
      ...
    </cascadeSummingCorrections>
    <elapsedTime>11.719</elapsedTime>
  </angle>
```

APPENDIX D. THEORETICAL BACKGROUND

D.1 INTRODUCTION

In any gamma-spectrometric measurement with semiconductor detectors, the task of **converting the number of counts** – collected by a multichannel analyzer (MCA) in a full gamma-energy peak – **into the activity of the sample/source** cannot be avoided. There are, in principle, three approaches to this issue: relative, absolute, and semi-empirical.

The relative method is more accurate, but less flexible to changing experimental conditions, while absolute ones are beautifully exact and flexible, but often too demanding where the extent and accuracy of the required input data are concerned.

The semi-empirical approach takes advantage of the positive attributes of both the relative and absolute methodologies, simultaneously minimizing their drawbacks. This brings us to the determination of full-energy peak efficiency (ε_p), an energy dependent characteristic of the detector for a given counting arrangement. Semi-empirical methods commonly consist of two parts: experimental (producing reference efficiency characteristic of the detector) and relative-to-this calculation of ε_p. The inherent inflexibility of the relative method is avoided in this way, as well as the demand for the many physical parameters needed in absolute calculations.

D.2 EFFICIENCY TRANSFER

Numerous variations exist within the semi-empirical approach, with regard to either the experimental or to the computational elements. It is important to note that only the simultaneous differential treatment of

- gamma-attenuation
- counting geometry
- detector response

can be justified. Attempting to separately calculate these three physical phenomena, generally leads to (over)simplifications, which further require complex corrections with the chance of only limited success.

This fact is transformed into the concept of the **effective solid angle** ($\overline{\Omega}$) – a calculated value incorporating the three components, and closely related to the detection efficiency. This assumes that the virtual peak-to-total ratio is in fact an intrinsic characteristic of the detector crystal (depending on gamma-energy only) and leads to ε_p being proportional to $\overline{\Omega}$. The detection efficiency is then found as:

$$\varepsilon_p = \varepsilon_{p,ref} \left(\overline{\Omega} / \overline{\Omega}_{ref} \right)$$

which is the basis of the **"efficiency transfer" principle**. Efficiency transfer factor (ET) is thus the ratio of the actual to reference efficiency at a given gamma-energy.

The ET approach is extremely useful, offering:

- practically unlimited flexibility in sample type and size, matrix composition, detector choice and source detector counting arrangement

- cancelling out much of the impact of input data uncertainties (especially those of the detector) on final ε_p calculation result

This implicit latter "ET error-compensation" lends to ET an important advantage over purely mathematical efficiency calculation approaches.

Therefore, in order to apply this method, the following should be known:

- **reference efficiency curve**, usually obtained by counting calibrated source(s) at reference geometry(ies) and covering gamma-energies in the region of interest; some effort should be put in into this phase to reach an accurate ε_p vs. E_γ function, as this fully pays off in further exploitation
- **geometrical and compositional data** about the source, detector, and all absorbing layers (source container and holder, detector end-cap and housing, dead layers, etc.)
- **gamma-attenuation coefficients** for all materials involved (normally a data file in the computer program).

ANGLE software is a computer software which performs these calculations. In its various forms, ANGLE has been in use for nearly 30 years now in numerous gamma-spectrometry based analytical laboratories worldwide.

The program can be applied to practically all situations encountered in gamma-laboratory practice: point, disk, cylindrical or Marinelli samples, small and large, of any matrix composition. No standards are required, but a start-up "**reference efficiency curve**" (**REC**) should be obtained ("once forever") by measuring a calibrated source at some reference counting geometry. Calibration sources should cover gamma-energy region of analytical interest (e.g., 50-3000keV). It is suggested that calibrated sources with low certified uncertainties (not exceeding 1.5%-2.5%) are used to obtain as many calibration points (efficiencies vs. gamma-energies) as possible for the energy range mentioned. This non-negligible initial effort is largely paid back in future exploitation, since an accurate reference efficiency curve is the basis for the accurate application of ANGLE.

One REC per detector is enough, in principle. It is recommended to construct it by counting a number of calibrated point sources at a large distance from the detector (e.g., 20-30 cm), avoiding true coincidences and matrix effects. Also, absolutely calibrated point sources are often certified to a better accuracy than voluminous ones.

It is generally more prudent to use **several single-nuclide sources**, than a single multi-nuclide source.

However, in order to additionally exploit the ET error-compensation effect, one might consider constructing more RECs for the same detector. For instance, the same point source(s) counted at a large distance could also be counted on the detector top, yielding another REC. Calibrated cylindrical and Marinelli sources could also produce additional RECs.

In an ideal case, using any of several RECs in ε_p calculations would produce the same result for the actual sample, i.e., the result should be independent of the choice of the REC. Given the fact that all input data (detector, source, geometry, etc.) are inaccurate to some extent, choosing a "**likely**" **REC** for the actual sample/geometry should eventually produce better (more accurate) results, due to a larger ET error-compensation effect. In other words, if the REC sample/geometry is closer to the actual sample, the results will tend to be better.

This in itself is a measure of the accuracy of the various sample and detector parameter choices – if two RECs produce results which are close, the implication is that both sample/geometry and detector are well characterized.

ANGLE allows multiple RECs to be employed for a given detector, so that varying the REC can be one of the elements in the optimization of gamma-spectrometry analytical procedure.
In short, ANGLE software is characterized by:

- broad application range, covering the vast majority of situations encountered in gamma-spectrometry practice
- high accuracy (uncertainties of calculated detector efficiencies are of the order of a few percent – usually less than that for other sources of uncertainty in the measurement), based upon the concept of the ET and effective solid angle calculations
- easy data manipulation with a friendly and intuitive graphical user interface
- short computation times of the order of seconds on standard PCs (normally not more than a minute even for the most complex calculations)
- flexibility with respect to changing input parameters, which enables easy estimation of the impact of a particular parameter on the detection efficiency and, related to this
- teaching/training aspect (for example, in gamma-spectrometry courses), since practically all parameters characterizing the detection process are found therein, systematically grouped and easy to follow and understand
- no need for any "factory characterization" of the detector – ANGLE can be used with any HPGE detector; when necessary, the detector performance is easily re-validated without intervention from the vendor
- possibility to expand, so as to meet changing users' counting conditions/requirements[2]
- the opportunity to accommodate other ET methods for efficiency calculations[2]

[2] Subject to request to the developers

THIS PAGE INTENTIONALLY LEFT BLANK.

APPENDIX E. GLOSSARY[3]

absolute method – quantification based on calculations only, implying physical parameters which characterize the detection process

absorbing layers – all absorbing materials between the source and the detector (including air)

amplifier – piece of electronics further amplifying the signal from a preamplifier

antimicrophonic shield – in some detectors, thin layer of low-Z material between the end-cap and the crystal, aimed at absorbing noise (mechanical vibrations) which disturbs the spectrum at low energies

attenuation – decrease in the intensity of a photon beam due to interaction with matter

calculation parameters – in ANGLE, this data is needed for an efficiency calculation to be performed, including those for: detector, radioactive source, and its container, counting geometry, gamma-energies of interest, reference efficiency curve and calculation precision

calibration source – source with certified (specific) activities of the radionuclides present

cascade summing – for some radionuclides, the effect of removal or pile up of counts in a full energy peak in the spectrum, due to simultaneous/cascade emission of photons in the decay schemes

coating layer – thin protective layer coating/lining the detector end-cap or source container

container foot – on some source containers, a small separation between the container bottom and the ground

counting arrangement – ensemble of the detector, source, container, holder and absorbing layers

counting geometry – see *geometry*

detection efficiency – characteristic of the counting arrangement (the ensemble of the detector, source, container, including their geometrical positioning, and all absorbing layers): probability that a photon emitted from the sample will be detected/recorded by the detector

detector – device for radiation detection

detector bulletization – rounding of the detector crystal edges in order to smooth out the electric field in the crystal, enabling better charge collection

detector calibration – experimental determination of the detection efficiency using calibration source(s)

[3] Definitions in this glossary are meant for facilitating the use of the ANGLE 5 User Guide, often simplified, and may vary from the exact meanings.

detector contact – electric contacts (electrodes) placed at the detector crystal, creating electric field therein; one of the contacts is normally the detector dead layer itself, the other may be, for example, a thin metal layer

detector crystal – active part of the detector, placed under high voltage and giving out the initial pulse from the energy deposited by the incoming photon

detector dead layer – inactive part of the detector crystal, usually at its surface

detector efficiency – characteristic of detector: detection efficiency at 1332 keV (Co-60 point source at 25 cm distance) as compared to 3 × 3" NaI detector (thus expressed in %); also called relative efficiency

detector end-cap – outer (visible) cap around the detector crystal, vacuum sealed

detector housing – inner physical support for the detector crystal

effective solid angle – compound parameter, closely related to detection efficiency, combining geometrical solid angle, attenuation effects and detection effects; the ratio between effective solid angle and *total efficiency* is 4 π

emission probability – probability that an atomic nucleus will emit radiation (e.g., gamma-ray) in unit time,

end-cap window – a portion at the top of the detector end-cap, which is made of lower Z material than the end-cap itself (e.g., beryllium or carbon fiber, while the end-cap is usually made of aluminium or magnesium)

full-energy peak – part of the spectrum around characteristic gamma-energy for the given radionuclide

full-energy peak efficiency – see *peak efficiency*

gamma-rays – photons emitted from atomic nucleus; gamma-energies range (at the low end) partially overlaps with X-rays range (at the high end)

gamma-spectrometry – quantitative determination of radionuclides present in the sample

gamma-spectroscopy – qualitative determination of radionuclides present in the sample

gamma-spectrum – result of spectroscopic measurement, distribution of recorded counts vs gamma-energies

GammaVision/Maestro – ORTEC's spectroscopy software

Gauss coefficient – number of integration segments in the Gauss-Legendre numerical integration method; higher coefficient yields better calculation precision, but slower calculations

Genie 2000 (Genie 2K) – Canberra's spectroscopy software

geometry (counting geometry) – in ANGLE this denotes the position of the source vs. the detector, including source holder and absorbing layers

holder (source support) – something that keeps the source at certain position vs the detector during counting

intercepting layers – see *absorbing layers*

Marinelli container (beaker) – source container in a form which enables the source to be closely positioned around the detector, yielding high detection efficiency

Monte Carlo method – computational algorithms that rely on repeated random sampling to obtain numerical results

multichannel analyzer – piece of electronics where signals are sorted according to their intensity, which is proportional to the photon energy deposited in the crystal

peak area – net number of counts in the peak (i.e., with spectrum background subtracted)

peak efficiency – detection efficiency, taking into account only full deposition of photon energy in the detector

photon – the quantum of electromagnetic radiation, having the properties of both the particles and waves (including gamma and X-rays)

preamplifier – piece of electronics which performs initial amplification of the signal/charge obtained from the photon

quantification – step from qualitative to quantitative results

quasi-relative method – a semi-empirical method in which counting arrangements for the sample and the source are not exactly the same (as is the case for the relative method), but the difference is not great

radioactivity – spontaneous, probability-related (stochastic), transformation of atomic nucleus, followed by the emission of radiation (e.g., in the form of alpha, beta or gamma-rays)

radionuclide – atomic nucleus which is radioactive

reference efficiency curve – result of detector calibration, detection efficiency vs energy for the given counting arrangement and calibration source(s), in ANGLE, serves as a reference parameter for calculated efficiencies

relative method – quantification based on standards (sources with a known activity)

sample – source of unknown activity (which is to be determined)

scintillation detector – device for photon detection, having a scintillator crystal (usually NaI) as an active body

self-attenuation – attenuation of photon beams within the source itself

self-standing source – solid source (e.g., in the form of a pill) which can stand on the holder on its own (i.e., without a container)

semiconductor detector – device for photon detection, having a semiconductor crystal as an active body, usually high-purity germanium (HPGe)

semi-empirical method – quantification based partly on standards, partly on calculations

source – radioactive material

specific activity – activity per mass unit

spectrometer – a device used to register and analyze gamma-rays emitted from the source in a specific range of energies; gamma-energies range (its low end) partially overlaps with X-rays range (its high end), roughly at 20 – 100 keV

spectrometry – see *gamma-spectrometry*

spectroscopy – see *gamma-spectroscopy*

standard – source with known/certified activity, usually from a specialized manufacturer

total efficiency – detection efficiency, taking into account any (full or partial) deposition of photon energy in the detector; the ratio between *effective solid angle* and total efficiency is 4 π

true coincidence summing – see *cascade summing*

vacuum (detector vacuum) – vacuum space between the crystal and end-cap

X-rays – photons emitted from atomic electron shell; range of X-rays (its high end) partially overlaps with range of gamma-energies (its low end), roughly at 20–100 keV