Technical Meeting on In-situ Methods for Characterization of Contaminated Sites
IAEA, Vienna, Austria, 5 – 9 July 2010

The Effective Solid Angle Concept and ANGLE v3.0 Computer Code for Semiconductor Detector Gamma-Efficiency Calculations

– Applicability to In-situ Characterization of Contaminated Sites –

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Gamma-Energy Peak Efficiency

In any gamma-spectrometric (quantitative) measurement with semiconductor detectors, the question of converting the number of counts - collected by multichannel analyser (MCA) in a full energy peak - into the activity (concentration) of the sample/source cannot be avoided.

There are, in principle, three approaches to this issue, as follows.

1) Relative, where one tries to imitate as good as possible the source by a standard (or vice versa), while keeping the same counting conditions for the two. Paid enough care, the result is, in general, so accurate that cannot be surpassed by other methods.

However, we all know what "enough care" means in practice. Combined with the inflexibility in respect with varying source&container parameters (shape, dimensions, material composition), this represents *raison d'être* of the other approaches, as follows.

2) **Absolute** calculations (Monte Carlo methods) yield full energy peak efficiency (ε_p) or total efficiency (ε_{tot}) for a given counting arrangement.

It is essentially **statistical treatment** of the events which photons undergo - from being emitted by a source atom until the interaction with the detector active body - including the treatment of the so produced electrons, positrons and other subsequent energy carriers.

Absolute approach is beautifully exact, on condition that we consider sufficiently large number of incident photons and that we know all the details about

- source, detector and intercepting layers‘ geometrical and compositional data
- the corresponding photon attenuation coefficients
- energy and angle dependent cross section for various photon interactions with the detector active body, and
- parameters characterizing electron/positron behaviour in the latter

At present, inherent statistical uncertainty of Monte Carlo methods, unsatisfactory manufacturers' detector specifications and relatively poor knowledge of the above physical parameters (some of) are limiting factors for its applicability.

3) Semiempirical models, trying to conciliate the previous two. Semiempirical models commonly consist of two parts:

- experimental (producing one kind or another of reference efficiency characteristic of the detector) and
- relative-to-this (‘efficiency transfer” – ET) calculation of ε_p

Inflexibility of the relative method is avoided in this way, as well as the demand for some physical parameters needed in Monte Carlo calculations.

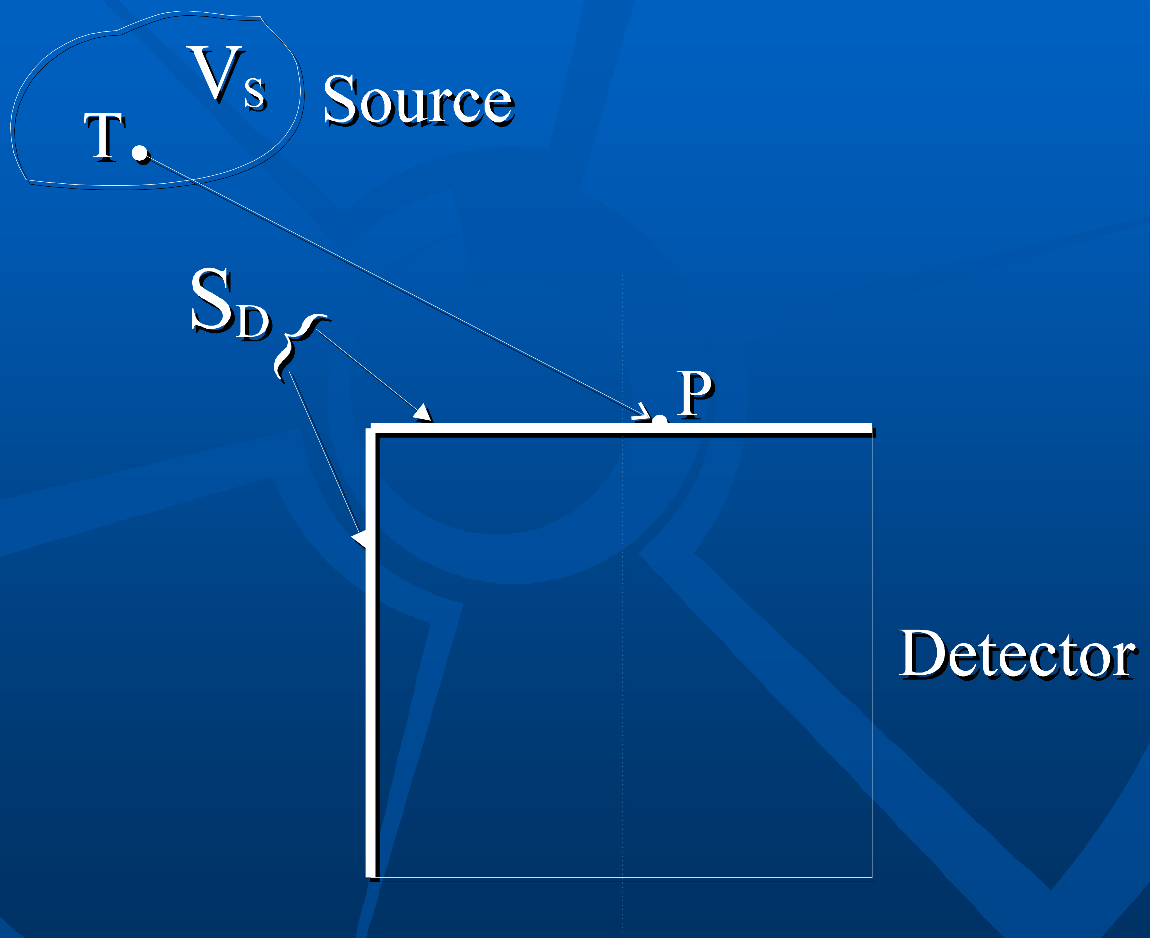
ET contributes significantly to error compensation in ε_p.

Numerous variations exist within this approach, with emphases either to experimental or to computational part. Most of them simplify (or oversimplify) the physical model behind, i. e. the treatment of

- gamma-attenuation
- geometry and
- detector response

It was shown earlier (within the development of the k0-NAA method) that only simultaneous differential treatment of these three factors is essentially justified. 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.

Theoretical



To the definition of the effective solid angle ($\overline{\Omega}$)

Theoretical

Given a gamma-source and a semiconductor detector, the effective solid angle is defined as:

$$\overline{\Omega} = \int_{V_S, S_D} d\overline{\Omega}$$

with V_S = source volume, S_D = detector surface exposed to the source ("visible" by the source) and

$$d\overline{\Omega} = \frac{F_{att} \cdot F_{eff} \cdot \mathbf{TP} \cdot \mathbf{n}_u}{|\mathbf{TP}|^3} d\sigma$$

Here T is point varying over VS, P point varying over SD, and ***nu*** the external unit vector normal to infinitesimal area $d\sigma$ at S_D. Eq. (1) is thus a five fold integral.

Factor F_{att} accounts for gamma attenuation of the photon following the direction TP out of the detector active zone, while F_{eff} describes the probability of an energy degradable photon interaction with the detector material (i.e. coherent scattering excluded), initiating the detector response.

The two factors include therefore geometrical and compositional parameters of the materials traversed by the photon.

Theoretical

With ε_p being proportional to $\overline{\Omega}$, the detection efficiency is found as:

$$\varepsilon_p = \varepsilon_{p,ref} \frac{\overline{\Omega}}{\overline{\Omega}_{ref}}$$

where index "ref" denotes reference counting geometry to which the actual one is relative.

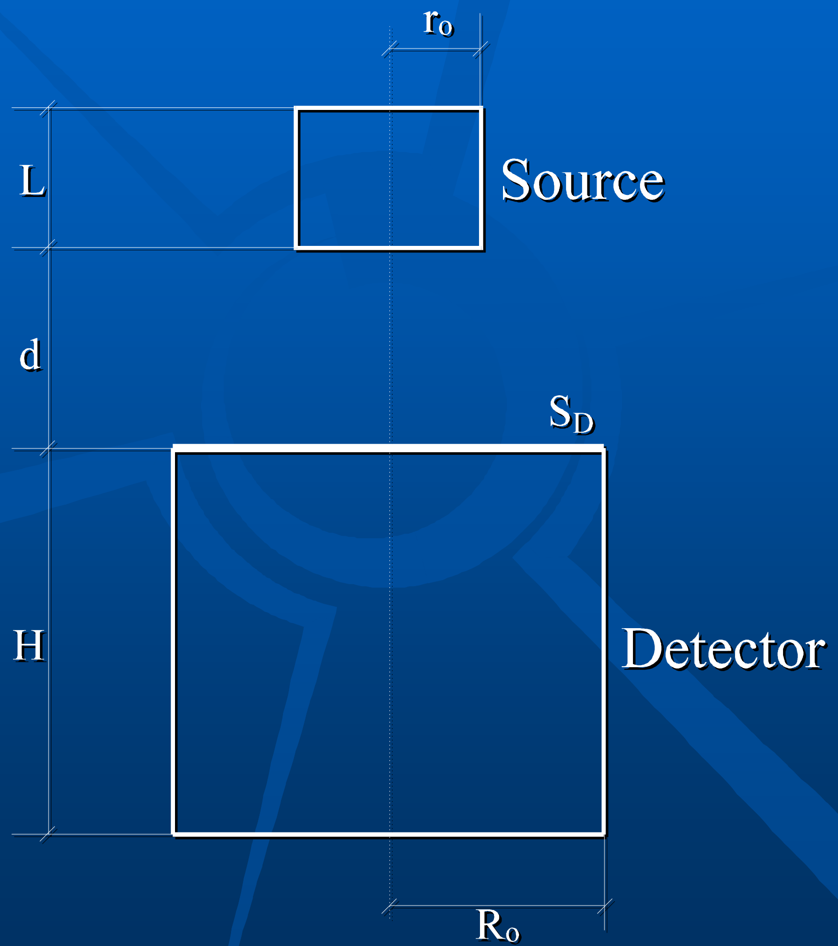
The above ratio reduces, even significantly, error propagation from input (e.g. detector) data !

Theoretical

So as to apply this method the following should be known:

- reference efficiency curve (REC), usually obtained by counting calibrated point sources at a reference distance (e. g. 15-20 cm), and covering gamma-energies (E_γ) in the region of interest (e. g. 50 -3000 keV); considerable effort should be put in this phase to reach accurate (E_γ) function, but it pays off in further exploitation;
- geometrical and compositional data about
  - source
  - detector
  - intercepting layers (source container and holder, detector end cap and housing, dead layers, etc.);
- gamma-attenuation coefficients for all materials involved

Theoretical



Cylindrical source ($r_0 < R_0$)

Theoretical

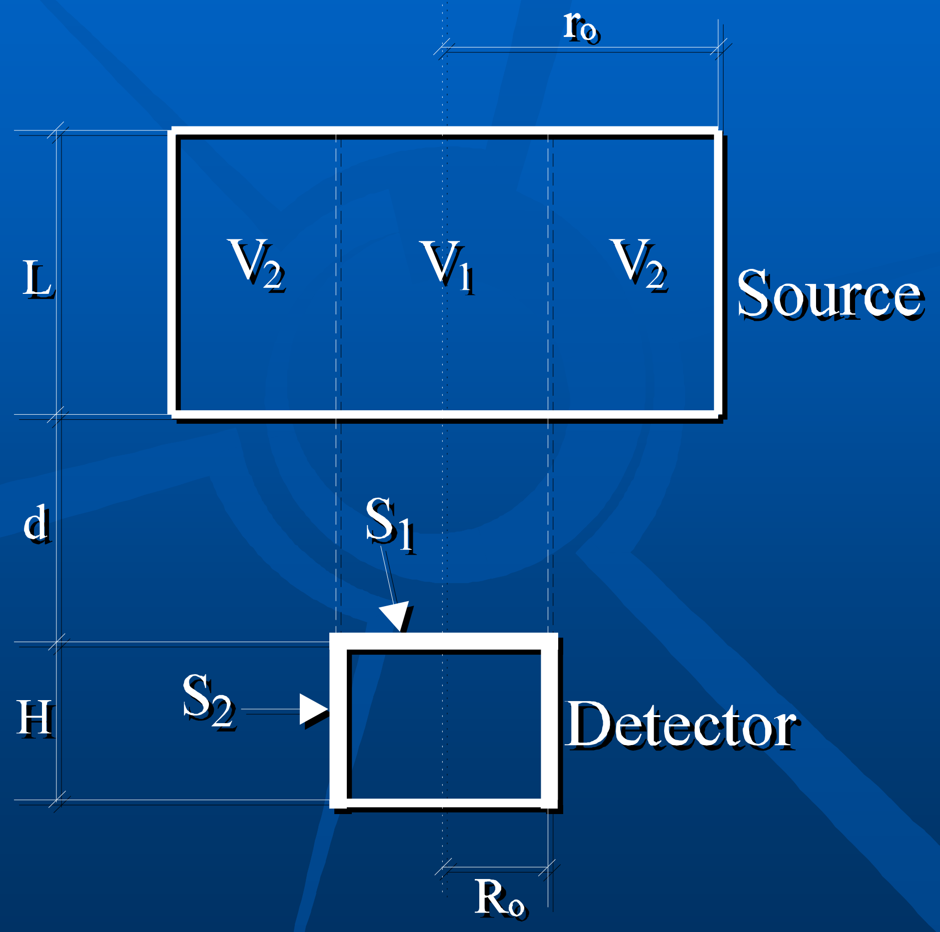
For a cylindrical source coaxially positioned with the detector, and with radius smaller than that of the detector ($r_0 < R_0$):

$$\overline{\Omega} = \frac{4}{r_o^2 L} \int_0^L (d+l)\, dl \int_0^{r_o} r\, dr \int_0^{\pi} d\phi \int_0^{R_o} \frac{F_{att} \cdot F_{eff} \cdot R\, dR}{\left[R^2 - 2Rr\cos\phi + r^2 + (d+l)^2\right]^{3/2}}$$

In the above, five fold integral is reduced to four fold due to axial symmetry. Disk and point sources are included in equation (for L=0, and L=0, r_0=0, respectively).

(SOLANG, KAYZERO/SOLCOI)

Theoretical



Cylindrical source ($r_0 > R_0$)

Theoretical

For sources with radii larger than that of the detector ($r_0 > R_0$) we obtain:

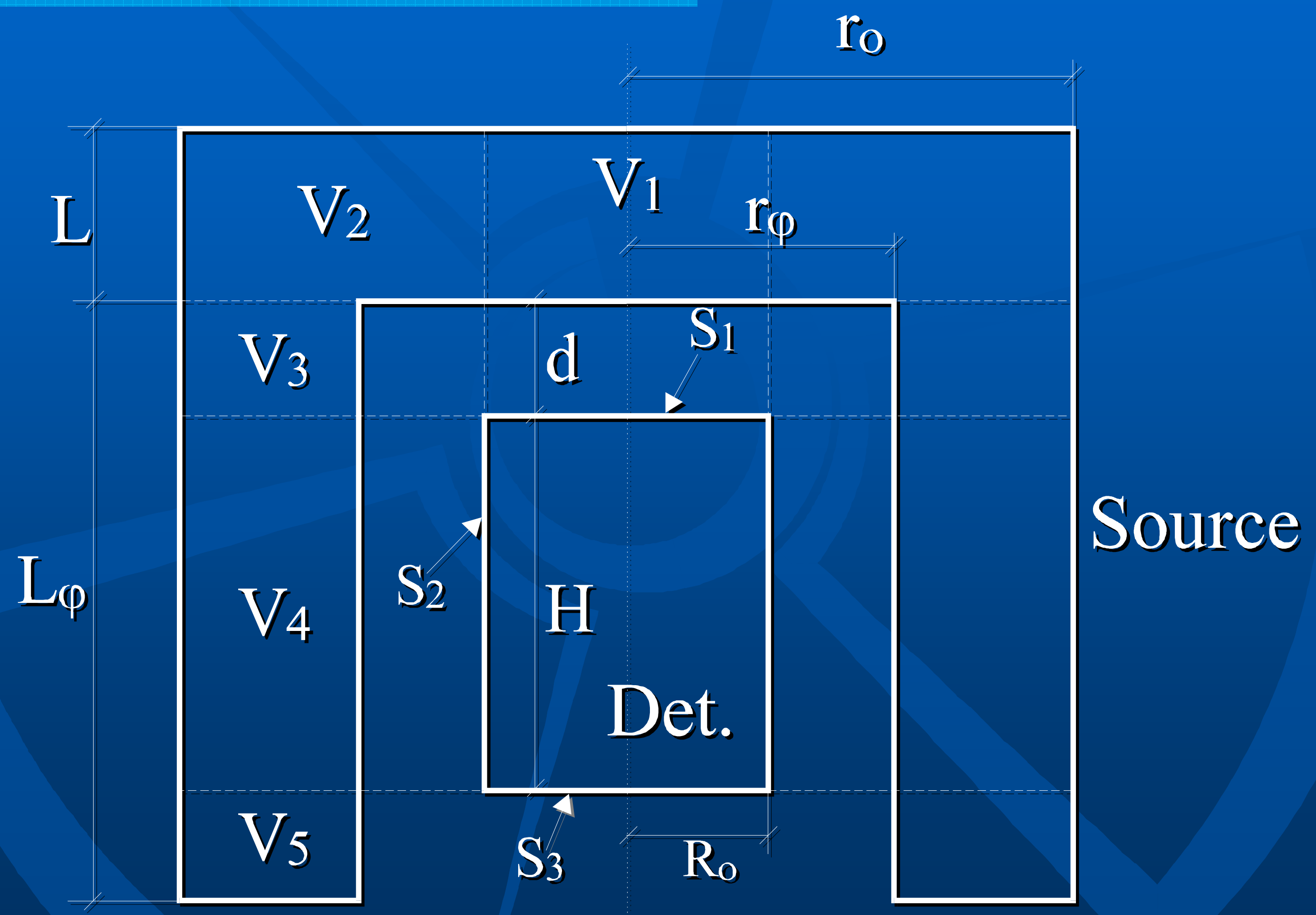
$$\overline{\Omega} = \int_{V_1,S_1} d\overline{\Omega} + \int_{V_2,(S_1+S_2)} d\overline{\Omega} =$$

$$= \frac{4}{r_o^2 L} \int_0^L (d+l)\,dl \int_0^{r_o} r\,dr \int_0^{\pi} d\phi \int_0^{R_o} \frac{F_{att} \cdot F_{eff} \cdot R\,dR}{\left[R^2 - 2Rr\cos\phi + r^2 + (d+l)^2\right]^{3/2}} +$$

$$+ \frac{4R_o}{\left(r_o^2 - R_o^2\right)L} \int_0^L dl \int_{R_o}^{r_o} r\,dr \int_0^{\phi_o} d\phi \int_{-H}^{0} \frac{F_{att} \cdot F_{eff} \cdot \left(r\cos\phi - R_o\right)dh}{\left[R_o^2 - 2R_o r\cos\phi + r^2 + (d+l-h)^2\right]^{3/2}}$$

with $\phi_o = \phi_o(r) = \operatorname{arctg}\frac{\sqrt{r^2 - R_o^2}}{R_o}$

Theoretical



Marinelli geometry

Theoretical

Marinelli geometry can be described as:

$$\overline{\Omega} = \int_{(V_1+V_2),S_1} d\overline{\Omega} + \int_{V_2,S_2} d\overline{\Omega} + \int_{V_3,S_1} d\overline{\Omega} + \int_{(V_3+V_4),S_2} d\overline{\Omega} + \int_{V_5,(S_2+S_3)} d\overline{\Omega} =$$

$$= \frac{4}{r_o^2 L + \left(r_o^2 - r_\varphi^2\right) L_\varphi} \int_0^L (d+l)\,dl \int_0^{r_o} r\,dr \int_0^{\pi} d\phi \int_0^{R_o} \frac{F_{att} \cdot F_{eff} \cdot R\,dR}{\left[R^2 - 2Rr\cos\phi + r^2 + (d+l)^2\right]^{3/2}} +$$

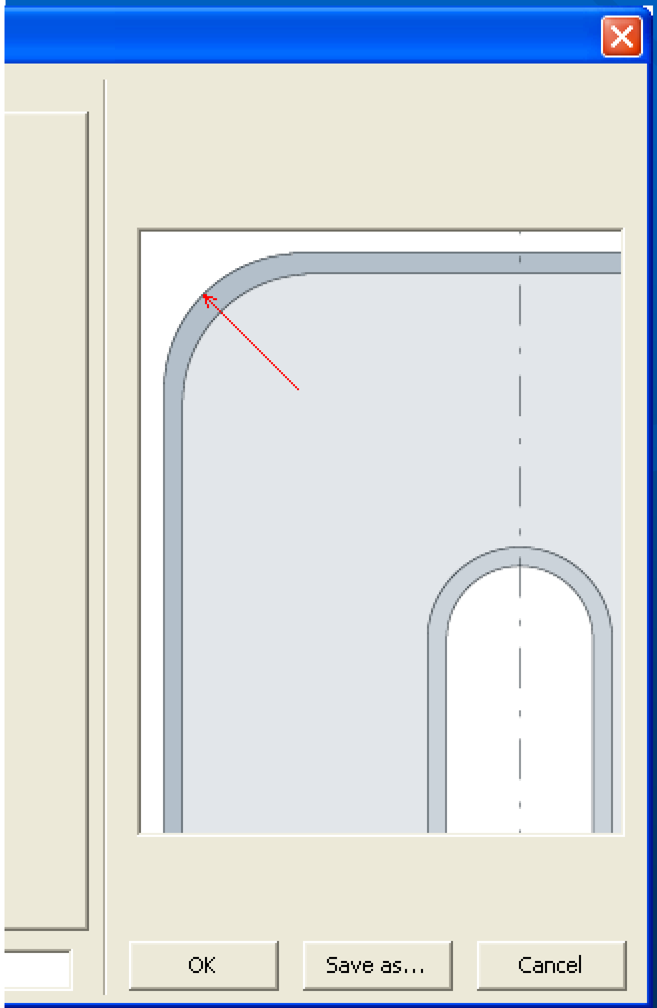
$$+ \frac{4R_o}{r_o^2 L + \left(r_o^2 - r_\varphi^2\right) L_\varphi} \int_0^L dl \int_{R_o}^{r_o} r\,dr \int_0^{\phi_o} d\phi \int_{-H}^{0} \frac{F_{att} \cdot F_{eff} \cdot \left(r\cos\phi - R_o\right) dh}{\left[R_o^2 - 2R_o r\cos\phi + r^2 + (d+l-h)^2\right]^{3/2}} +$$

$$+ \frac{4}{r_o^2 L + \left(r_o^2 - r_\varphi^2\right) L_\varphi} \int_0^d l\,dl \int_{r_\varphi}^{r_o} r\,dr \int_0^{\pi} d\phi \int_0^{R_o} \frac{F_{att} \cdot F_{eff} \cdot R\,dR}{\left(R^2 - 2Rr\cos\phi + r^2 + l^2\right)^{3/2}} +$$

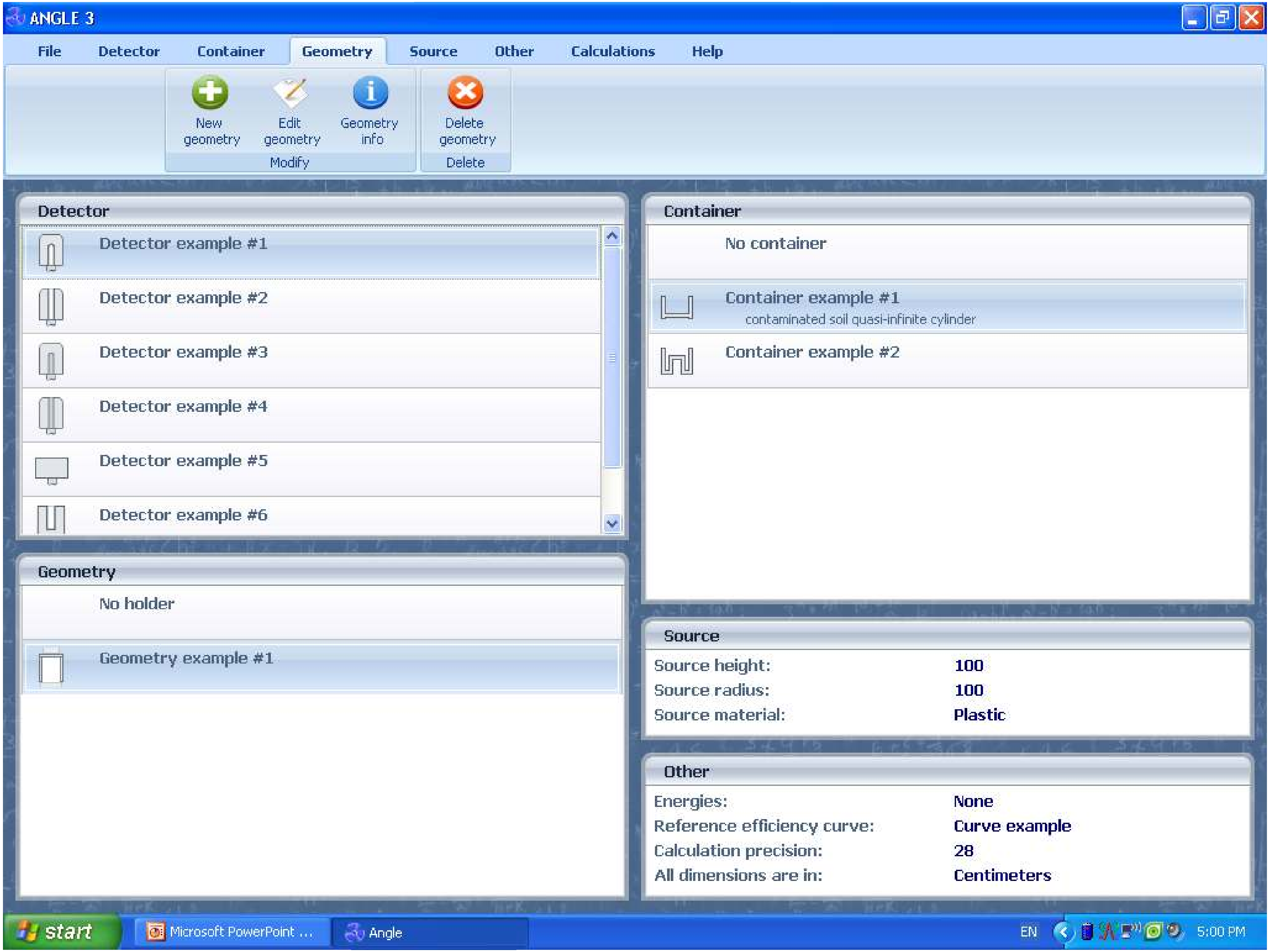
$$+ \frac{4R_o}{r_o^2 L + \left(r_o^2 - r_\varphi^2\right) L_\varphi} \int_{d-L\varphi}^{d} dl \int_{r_\varphi}^{r_o} r\,dr \int_0^{\phi_o} d\phi \int_{-H}^{0} \frac{F_{att} \cdot F_{eff} \cdot \left(r\cos\phi - R_o\right) dh}{\left[R_o^2 - 2R_o r\cos\phi + r^2 + (l-h)^2\right]^{3/2}} +$$

$$+ \frac{-4}{r_o^2 L + \left(r_o^2 - r_\varphi^2\right) L_\varphi} \int_{d-L\varphi}^{-H} (l+H)\,dl \int_{r_\varphi}^{r_o} r\,dr \int_0^{\pi} d\phi \int_0^{R_o} \frac{F_{att} \cdot F_{eff} \cdot R\,dR}{\left[R^2 - 2Rr\cos\phi + r^2 + (l+H)^2\right]^{3/2}} \quad (6)$$

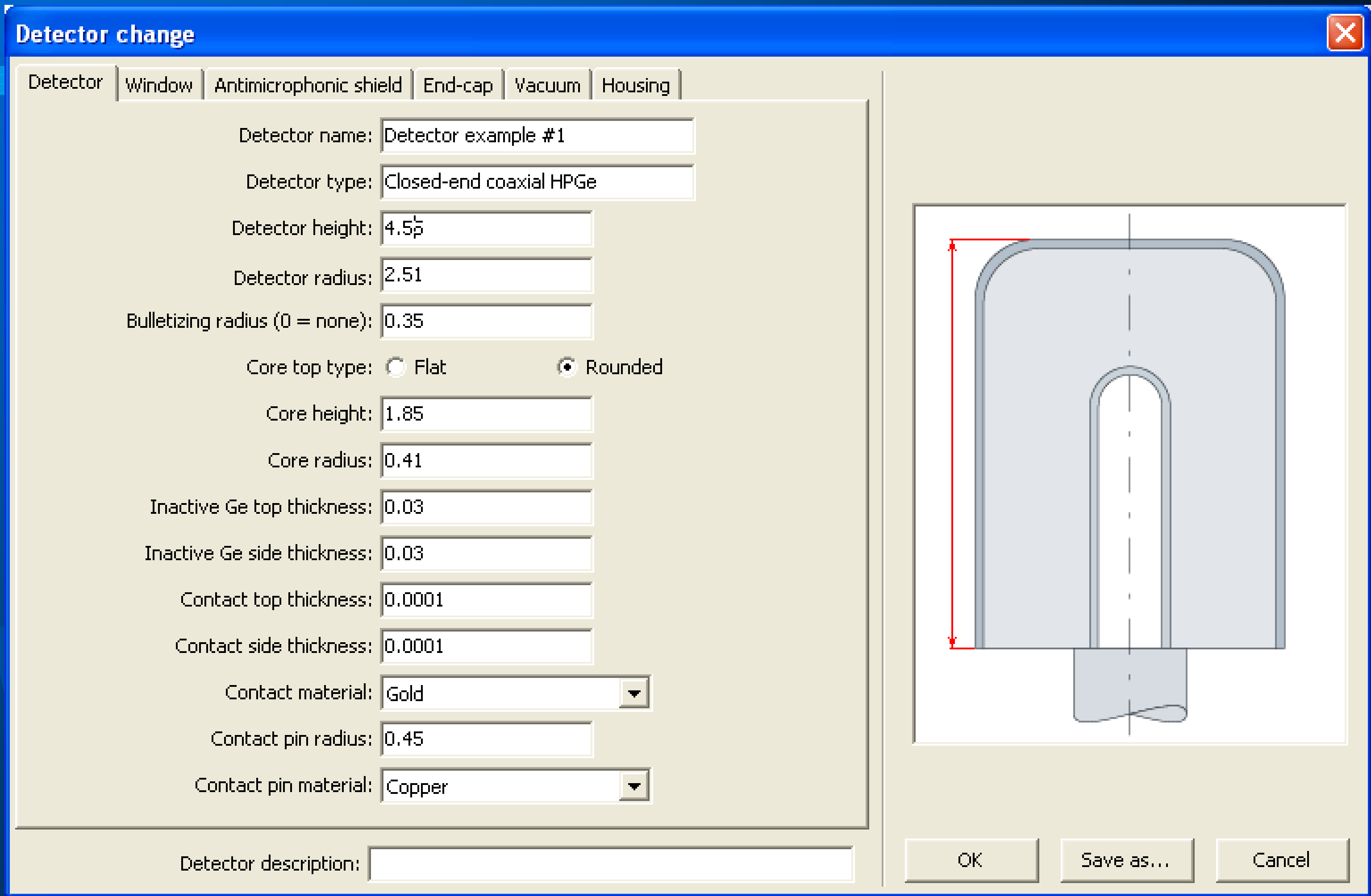
Accounting for detector crystal edge rounding ("bulettizing")



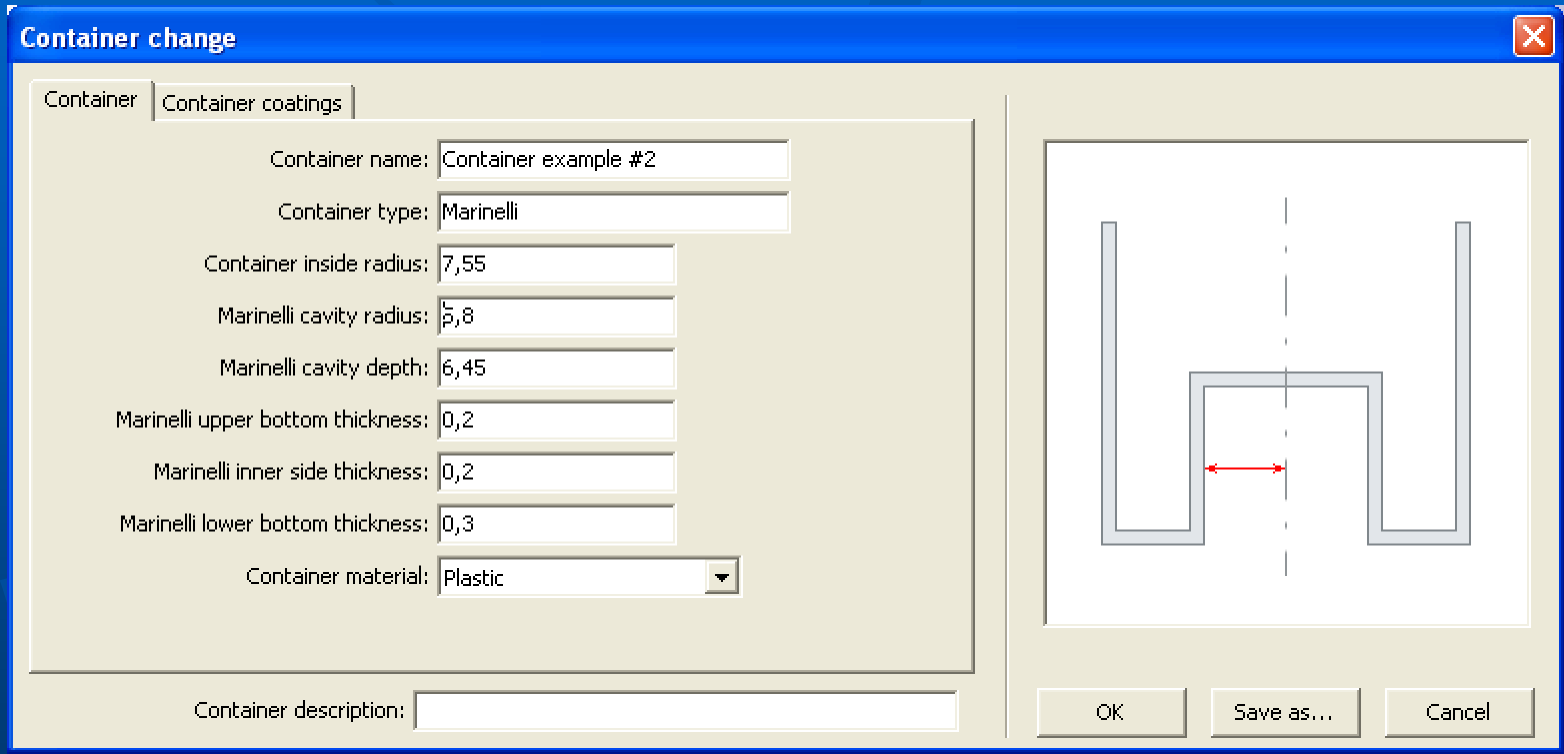
$$
\begin{aligned}
\bar{\Omega} = {} & \frac{4}{r_0^2 L + \left(r_0^2 - r_\varphi^2\right)\angle\varphi} \int_0^L dl \int_0^{r_0} rdr \int_0^{\pi} d\theta \int_0^{R_0-\rho} F_{att} F_{eff} F_1(T, P_{S_1}) RdR + \\
& + \frac{4}{r_0^2 L + \left(r_0^2 - r_\varphi^2\right)\angle\varphi} \int_0^L dl \int_0^{r_0} rdr \int_0^{\pi} d\theta \int_{R_0-\rho}^{R_0} F_{att} F_{eff} F_{13}(T, P_{S_1}) RdR + \\
& + \frac{4R_0}{r_0^2 L + \left(r_0^2 - r_\varphi^2\right)\angle\varphi} \int_0^L dl \int_{R_0}^{r_0} rdr \int_0^{\theta_0} d\theta \int_{-H}^{R_0-\rho} F_{att} F_{eff} F_2(T, P_{S_2}) dh + \\
& + \frac{4R_0}{r_0^2 L + \left(r_0^2 - r_\varphi^2\right)\angle\varphi} \int_0^L dl \int_{R_0}^{r_0} rdr \int_0^{\theta_0} d\theta \int_{-\rho}^{0} F_{att} F_{eff} F_{23}(T, P_{S_2}) dh + \\
& + \frac{4}{r_0^2 L + \left(r_0^2 - r_\varphi^2\right)\angle\varphi} \int_0^d dl \int_{r_\varphi}^{r_0} rdr \int_0^{\pi} d\theta \int_0^{R_0-\rho} F_{att} F_{eff} F_3(T_m, P_{S_1}) RdR + \\
& + \frac{4}{r_0^2 L + \left(r_0^2 - r_\varphi^2\right)\angle\varphi} \int_0^d dl \int_{r_\varphi}^{r_0} rdr \int_0^{\pi} d\theta \int_{R_0-\rho}^{R_0} F_{att} F_{eff} F_{33}(T_m, P_{S_1}) RdR + \\
& + \frac{4R_0}{r_0^2 L + \left(r_0^2 - r_\varphi^2\right)\angle\varphi} \int_{d-L_\varphi}^{d} dl \int_0^{r_0} rdr \int_0^{\theta_0} d\theta \int_{-H}^{-\rho} F_{att} F_{eff} F_4(T_m, P_{S_2}) dh + \\
& + \frac{4R_0}{r_0^2 L + \left(r_0^2 - r_\varphi^2\right)\angle\varphi} \int_{d-L_\varphi}^{d} dl \int_0^{r_0} rdr \int_0^{\theta_0} d\theta \int_{-\rho}^{0} F_{att} F_{eff} F_{43}(T_m, P_{S_2}) dh - \\
& - \frac{4}{r_0^2 L + \left(r_0^2 - r_\varphi^2\right)\angle\varphi} \int_{d-L_\varphi}^{-H} dl \int_{r_\varphi}^{r_0} rdr \int_0^{\pi} d\theta \int_0^{R_0} F_{att} F_{eff} F_5(T_m, P_{S_4}) RdR
\end{aligned}
$$


ANGLE 3
File
Detector
Container
Geometry
Source
Other
Calculations
Help
New geometry
Edit geometry
Geometry info
Modify
Delete geometry
Delete
Detector
Detector example #1
Detector example #2
Detector example #3
Detector example #4
Detector example #5
Detector example #6
Container
No container
Container example #1
contaminated soil quasi-infinite cylinder
Container example #2
Geometry
No holder
Geometry example #1
Source
Source height: 100
Source radius: 100
Source material: Plastic
Other
Energies: None
Reference efficiency curve: Curve example
Calculation precision: 28
All dimensions are in: Centimeters
start
Microsoft PowerPoint ...
Angle
EN
5:00 PM

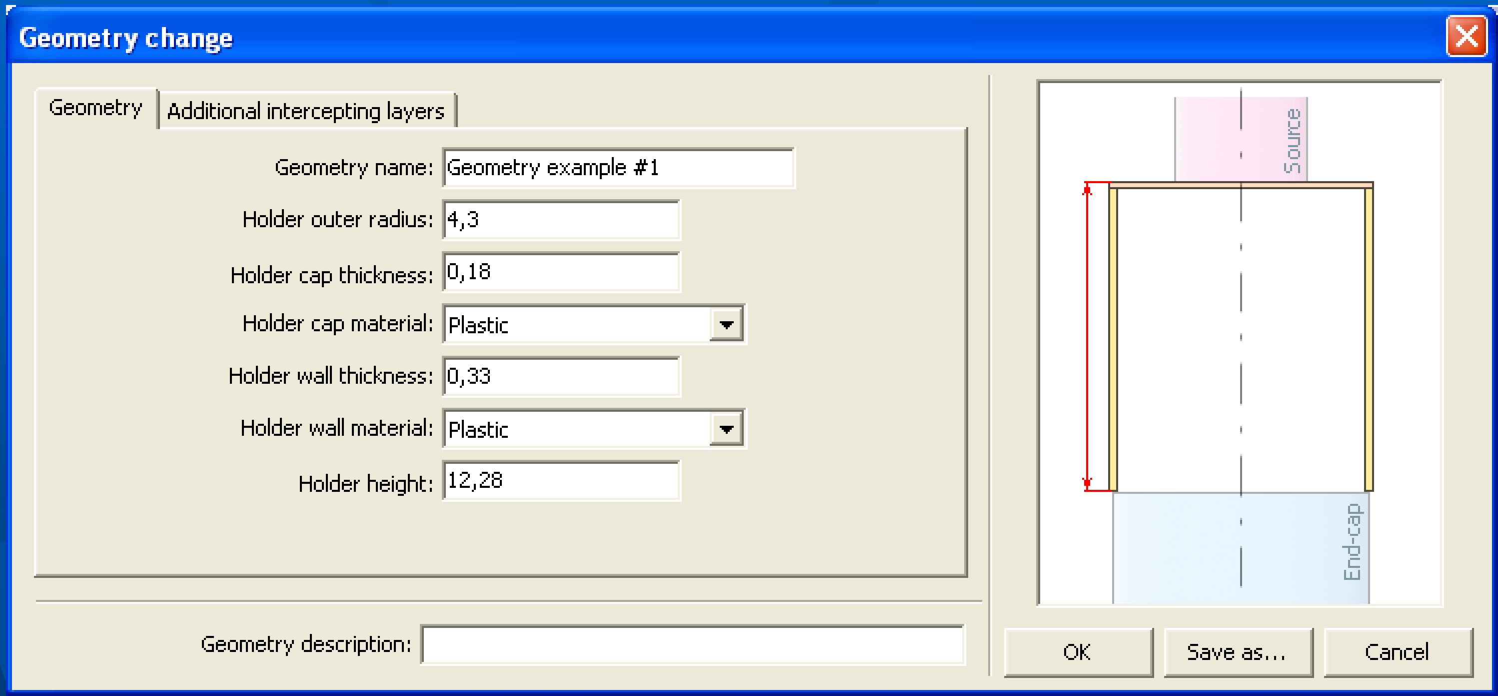
detector data input



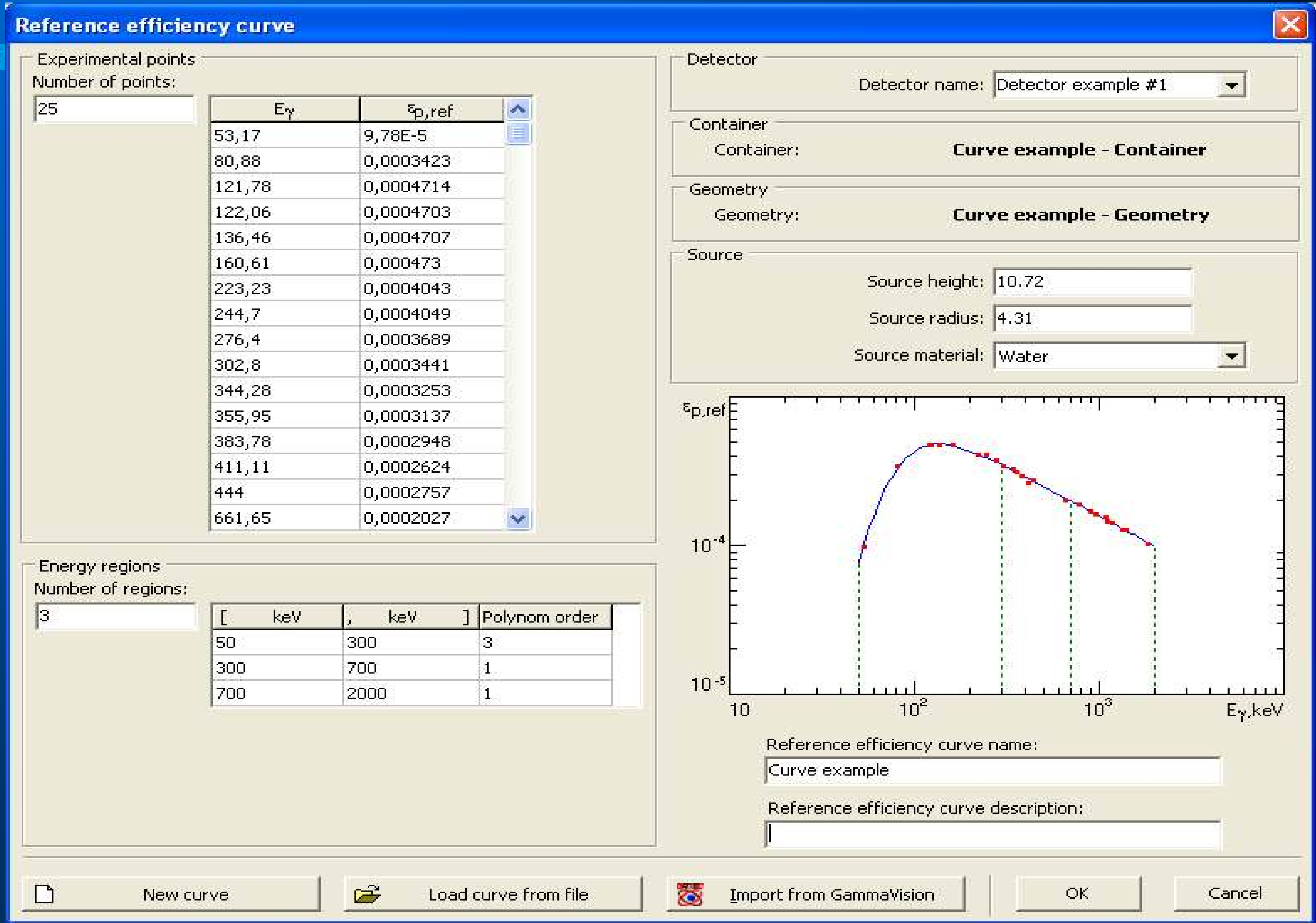
source container data input



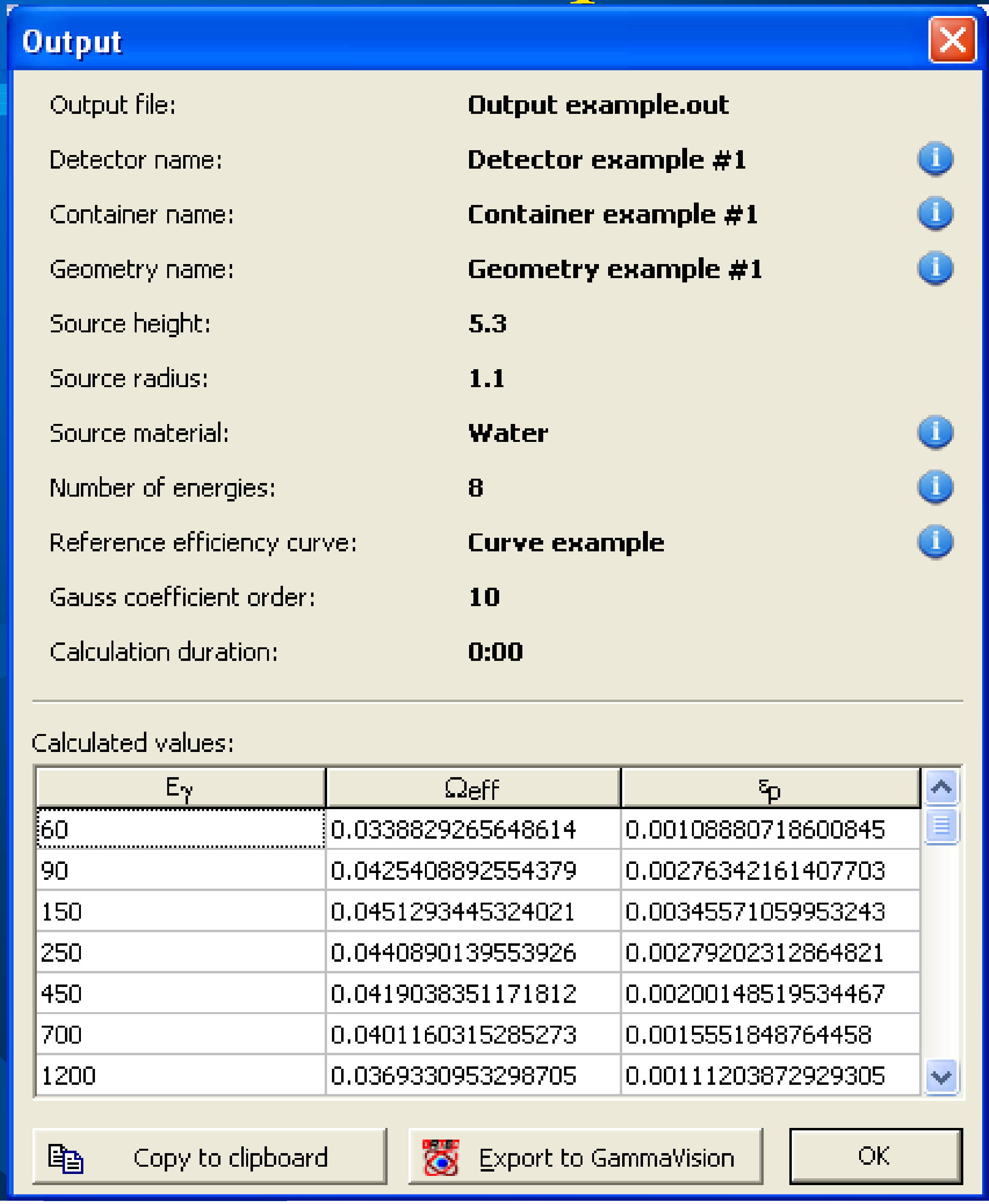
geometry data input



reference efficiency curve data input



output data file



E_γ	Ω_{eff}	ε_p
60	0.0338829265648614	0.00108880718600845
90	0.0425408892554379	0.00276342161407703
150	0.0451293445324021	0.00345571059953243
250	0.0440890139553926	0.00279202312864821
450	0.0419038351171812	0.00200148519534467
700	0.0401160315285273	0.0015551848764458
1200	0.0369330953298705	0.00111203872929305

ANGLE frame is also easily adjustable to other semiempirical or Monte Carlo models for efficiency calculations, since communication with the user (data input/output) is nearly the same

Possibilities

- Any type of commercial semiconductor detector (HPGe, Ge-Li, well, LEPD)
- Practically any type of typical gamma source (point, disk, cylinder, Marinelli)
- Extraordinary flexible and user-friendly 32-bit Windows application

Main Advantages:

- Broad application range
- High accuracy
- Easy data manipulation
- Short computation times
- Flexibility
- Teaching/training aspect
- No detector “factory characterization”

When assigning uncertainties to ANGLE calculation results, several **uncertainty-contributing components** should be distinguished, **originating from**

- Detector manufacturer
- ANGLE user and
- ANGLE software itself. These include:

- detector data, supplied by the manufacturer
- geometrical and compositional (chemical) data of the source, its container vessel and intercepting layers (between the source and the detector), introduced by the user
- reference efficiency curve, created or chosen by the user
- mathematical model and calculation method applied (ANGLE)
- gamma-attenuation coefficients and other physical/chemical parameter data used in calculations (ANGLE)

Testing Efficiency Transfer Codes for Equivalence

(paper submitted to Appl. Rad. Isot.)

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(e) Ahmadu Bello University, Zaria, Nigeria
(f) Commissariat à l'Énergie Atomique, Gif sur Yvette Cedex, France
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Table 4: The various combinations of the codes, their types and the ET implementations considered in the study

Computer Code	ET Implementation		Code Type	
	FEPE	ET	Specialized	General
ANGLE		x	x	
EFFTRAN		x	x	
DETEFF 4.2	x	x	x	
EGS4	x			X
GEANT 3.21	x	x		X
GESPECOR 4.2	x		x	
MCNP4C	x			X
MCNPX	x			X
PENELOPE 2003	x			X
PENELOPE 2008	x			X
PENELOPE PENCYL	x			X
ETNA		x	x	
MCNPX	x			X

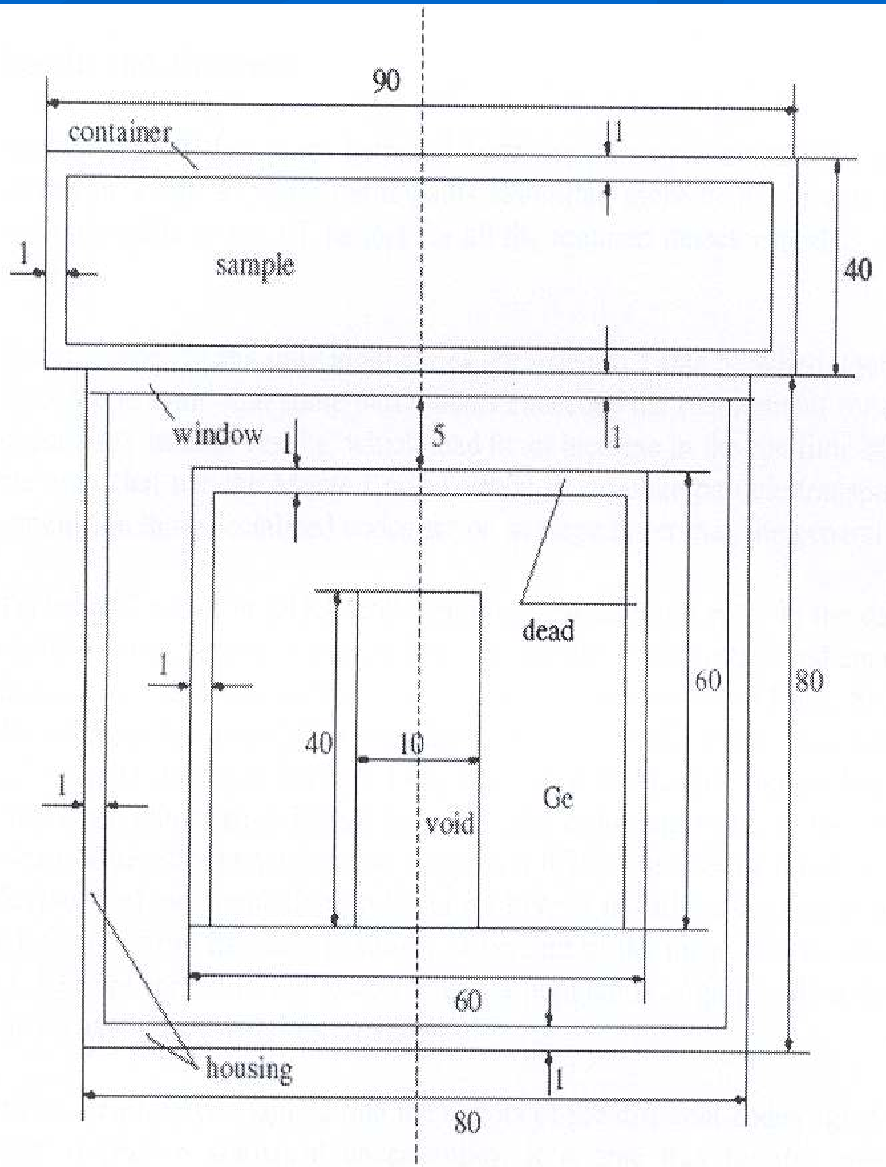


Figure 1: A schematic presentation of the setup for the case of the soil sample and the p-type detector model

Efficiency transfer (ET) from voluminous source (large cylinder, aquatic solution) to:

- Point source
- Large disc source (air filter paper)
- Cylinder (quartz matrix)

- n-type and p-type detectors
- Energy range 20 – 2000 keV

Table 7: Standard deviation of the population of the ET factors, as percent of its mean. The value exceeding 2% is marked in bold. The averaging and the standard deviation calculation were done over all the data sets (see text).

Energy	Point A	Point B	Soil A	Soil B	Filter A	Filter B
20		1.4		**2.5**		1.2
45	0.5	0.9	0.9	0.5	0.9	0.8
60	0.6	0.5	0.9	0.9	1.0	0.5
80	0.6	0.4	0.9	0.7	0.8	0.5
120	0.5	0.4	0.7	0.5	0.6	0.6
200	0.7	0.7	0.6	0.6	0.6	0.8
500	0.8	0.9	0.8	0.3	0.6	0.9
1000	0.7	1.1	0.5	0.5	0.8	0.9
2000	0.7	1.0	0.7	0.6	0.8	0.8

Table 8: The maximum deviation of the population of the ET factors from its mean, as percent of the mean. Values exceeding 2% are marked in bold.

Energy	Point A	Point B	Soil A	Soil B	Filter A	Filter B
20	-	**3.1**	-	**7.6**	-	3.4
45	1.2	1.7	**3.1**	1.3	**2.2**	1.4
60	1.2	1.1	1.9	**2.3**	**2.5**	1.0
80	1.2	1.0	2.0	1.6	2.0	1.1
120	0.9	0.8	1.8	1.6	1.2	1.1
200	1.1	1.4	1.2	1.6	1.2	1.4
500	1.4	1.9	1.7	0.5	1.1	1.5
1000	1.6	2.0	0.9	1.2	1.4	1.5
2000	1.9	1.9	1.5	0.9	1.4	1.3

- How far can our expectation go from detector manufacturers about detector data?
- What is a reasonable accuracy to expect from detector efficiency characterization?

Resolution - ______ keV (FWHM) @ 1.33 MeV
- ______ keV (FWTM)
- ______ keV (FWHM) @ ______
- ______ keV (FWTM)

Peak/Compton - ______ :1

Cryostat Description or Drw. No. if special Vertical dipstick, type 7500

6.2 PHYSICAL/PERFORMANCE DATA

Date: November 29, 1982

Actual performance of this detector when tested is given below. Digital printouts are also enclosed in the rear envelope of the instruction manual.

Geometry Coaxial one open end, closed end facing window.

Diameter 49.4 mm

Length 48 mm

Weight 480 gm

Active area facing window 18.7 cm^2

P-core Diameter 8 mm

P-core Length 25 mm

Distance from window 5 mm

Thickness of n-layer 0.3 mm

LEAKAGE CURRENT AND CAPACITANCE

Volts	nAmp	pf
100	0.010	279
200	0.010	220
300		
400		
500	0.010	160

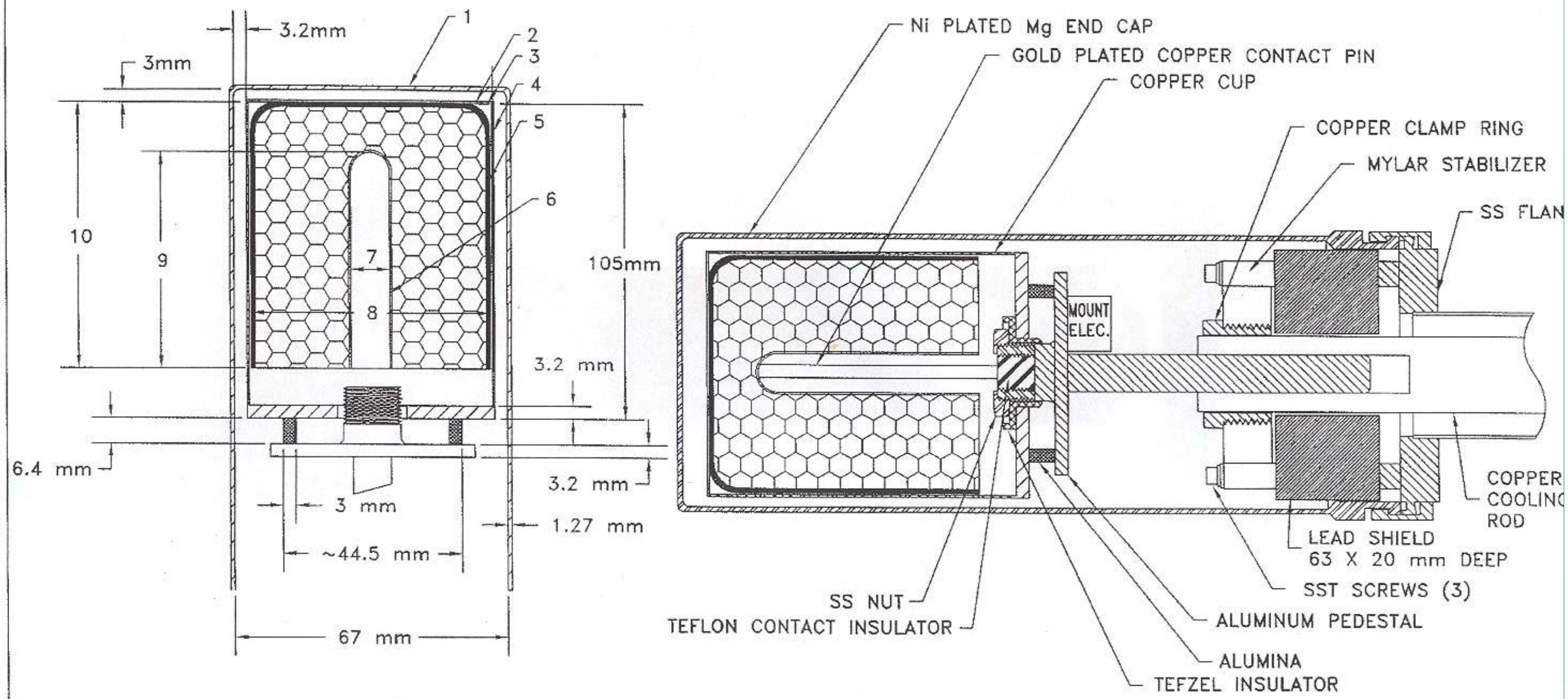
Volts	nAmp	pf
1000	0.010	111
1500	0.010	81
2000	0.010	66
2500	0.018	55
3000	0.031	50

Volts	nAmp	pf
3500	0.040	37
4000	0.050	35
4500	0.063	30
5000	0.068	26

Recommended Operating Voltage: (+) 5000 V

RESOLUTION AND EFFICIENCY

Isotope	Co^{57}	Cs^{137}	Co^{60}	Th^{228}	
Energy (keV)	122	662	1332	2614	
FWHM (keV)			1.87		



1. Ni plated Mg 1.27 mm
2. MYLAR 0.025 mm
3. ALUMINUM FOIL 0.025 mm
4. ALUMINUM CUP 0.50 mm
5. LITHIUM CONTACT 0.9 mm
6. BORON CONTACT 0.3 microns
7. HOLE DIAMETER 8.9 mm
8. CRYSTAL DIAMETER 59 mm
9. HOLE LENGTH 66.3 mm
10. CRYSTAL LENGTH 80.1 mm

EG&G ORTEC

100 MIDLAND ROAD, OAK RIDGE, TENNESSEE 37

MATERIALS & DIMENSION
DETECTOR # 38-P40896

DRAFTER DATE DLS 12-17-98	RESP ENG APP DATE	REFERENCE/USED ON
CHECKED	DESIGN ENGR	PROJECT
	MFG APPROVAL DATE	DRAWING NO.

- **Accuracy of detector specifications is limited by the technological process of their production (dead layer, vacuum, crystal impurities, crystal tilt/shift, …)**
- **Even two “identical” detectors from the production line may exhibit significantly different response to gamma-radiation**
- **Major positive impact is due to partial canceling of input uncertainties for reference and actual counting geometry**

(ET error compensation)

- If not satisfied with detector data, **more than one reference efficiency curve can be produced for the same detector** – so as to closer match the actual samples to the most similar reference one (this option is valid rather for environmental monitoring than for k0-NAA), e.g.
  - two point-source ref. eff. curves (0 cm and 20 cm)
  - one cylinder ref. eff. curve
  - one Marinelli ref. eff. curve

- Uncertainty should be estimated for each case separately, since depending on many factors (energy, geometry, input data reliability, …)

- Eventually , "uncertainty budget" shows that the best expected combined ε_p uncertainty would be:
  - **1-2% for point sources**
  - **3-4% for cylindrical source**
  - **5-7% for Marinelli**

    (<100 keV and >2000 keV: less reliable)

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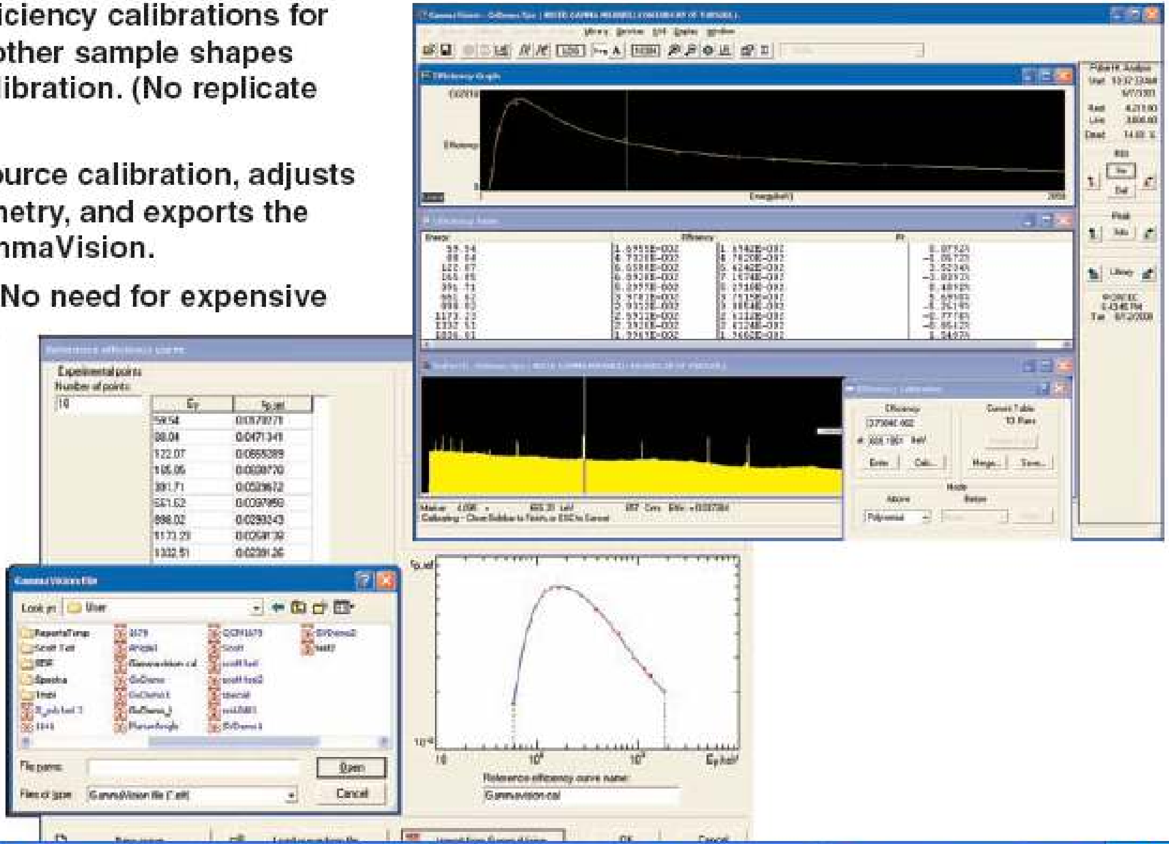
ANGLE

Advanced Efficiency Calibration Software for High Purity Germanium Detectors

- An easy way to create HPGe efficiency calibrations for Marinelli Beakers, bottles and other sample shapes directly from a point source calibration. (No replicate standards required.)
- Reads in GammaVision point source calibration, adjusts the calibration to the new geometry, and exports the revised calibration back to GammaVision.
- WORKS WITH ANY DETECTOR. No need for expensive and time consuming "return to factory" characterization.
- Works with a wide variety of HPGe Detector types from any manufacturer – templates included.
- Works with the majority of container types commonly found in Nuclear Counting Laboratories – templates included.
- Reduces radioactive waste disposal problems and lowers



- **Applicability to in-situ characterization of contaminated sites**

- **ANGLE is readily applicable to radioactivity measurements in the environment. Several possibilities are straightforwardly at user's disposal**

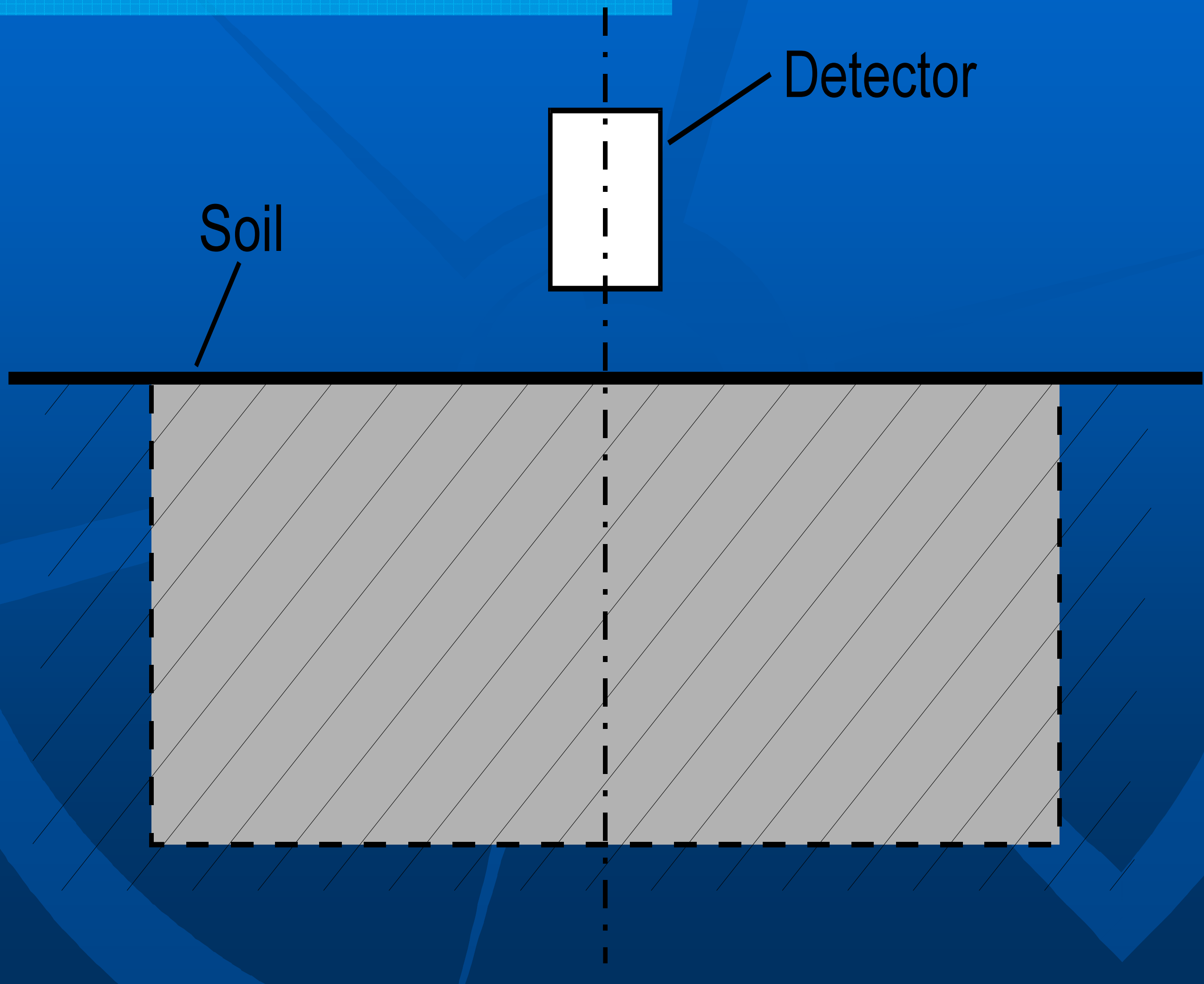
- **Regular" radioactivity measurements of**
  - **voluminous (solid or liquid) samples collected at contaminates sites (either in cylindrical or Marinelli beakers), or**
  - **filters collecting air radioactivity by means of air pumps ("disc" sources).**

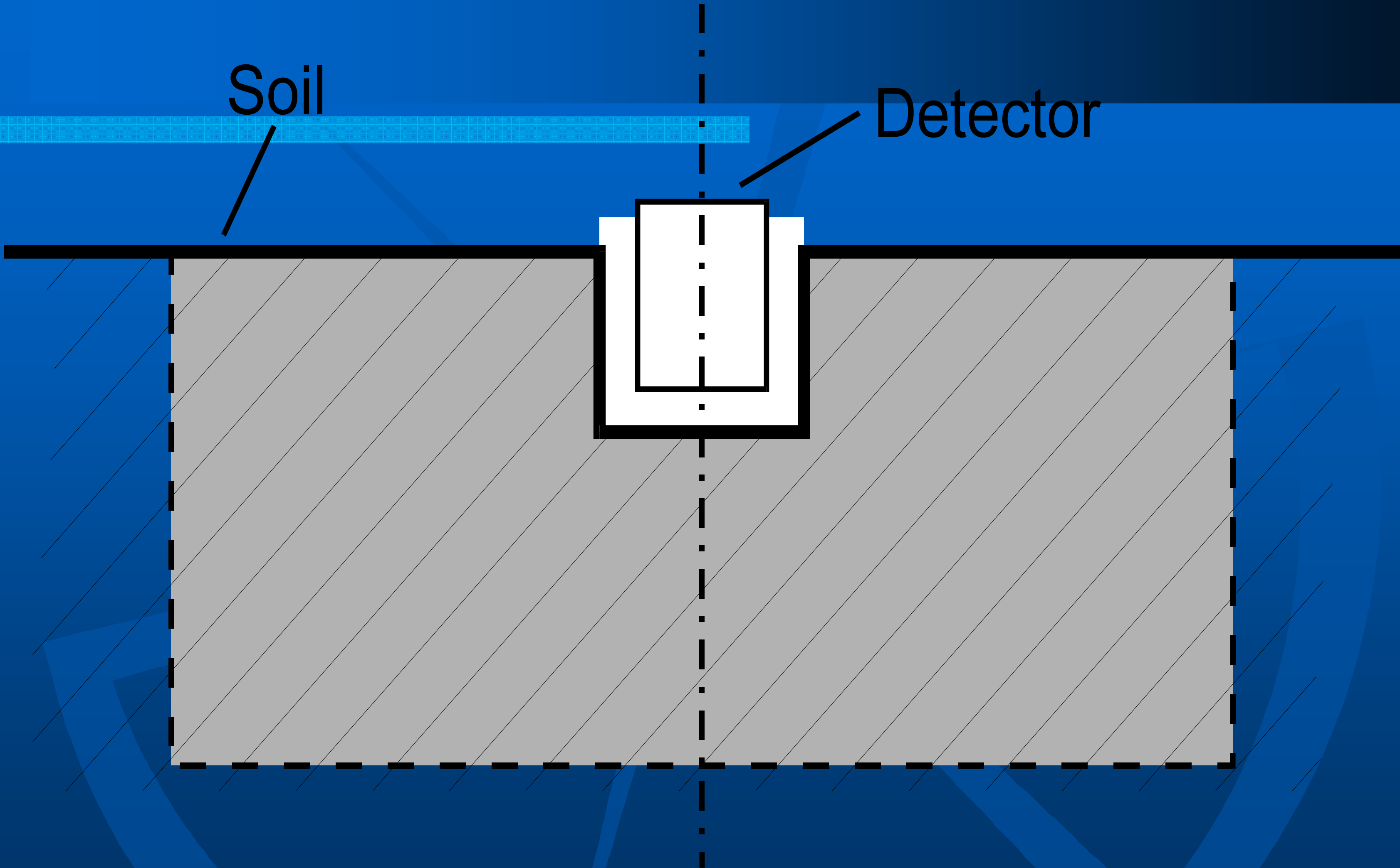
- **ANGLE supports these cases directly through combination of appropriate entries in *Source* and *Container* windows. Activity (A) of a particular nuclide is then simply derived from ANGLE-calculated full-energy detection efficiency and net gamma-peak area (N_p) recorded by multichannel analyzer (MCA) during counting time t_m :**

$$A \cdot \varepsilon_p = N_p / t_m$$

- Soil radioactivity can be measured by positioning the detector towards the ground or in a hole. These cases correspond to infinite cylinder and infinite Marinelli geometry, respectively. In practice, however, only limited area relatively close to the detector contributes relevantly to the measurement – outside that area the contribution is negligible, either because of the distance or attenuation, or both. 1m source radius (cylinder or Marinelli) usually is good enough approximation.

- Note this model assumes radioactivity to be homogeneously distributed in the soil. An illustration of data entry for quasi-infinite cylindrical source is given.

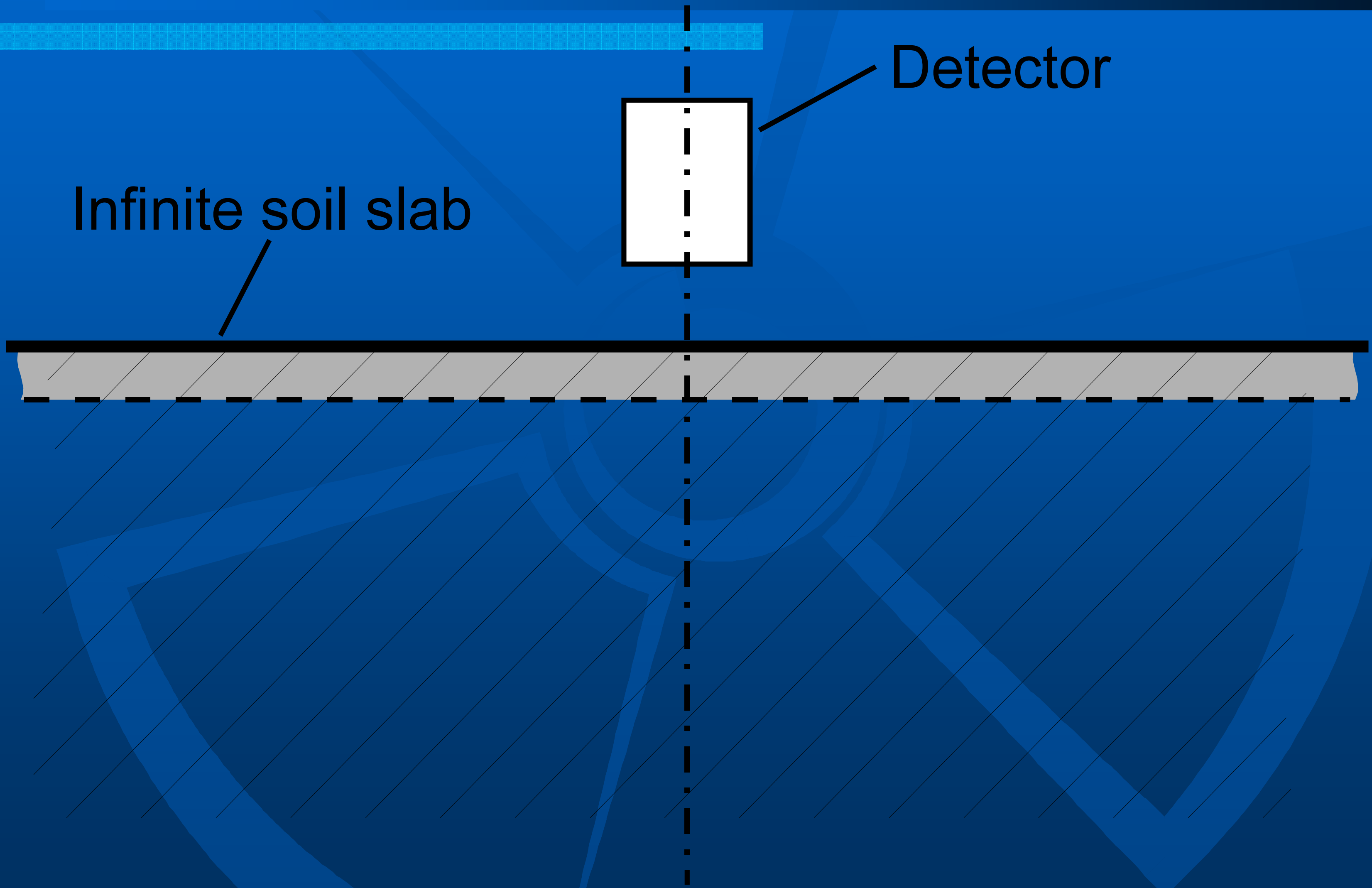

Detector
Soil

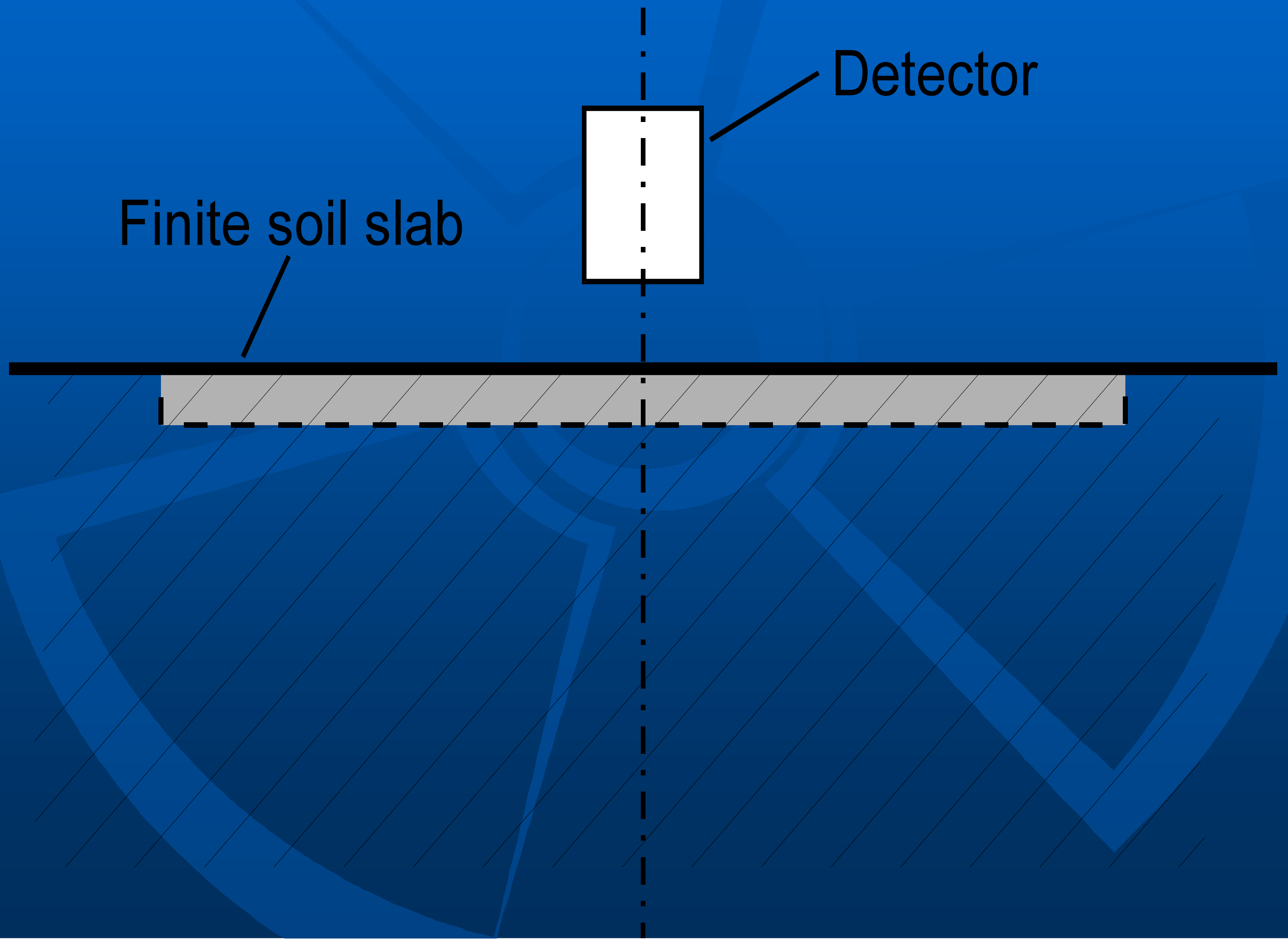


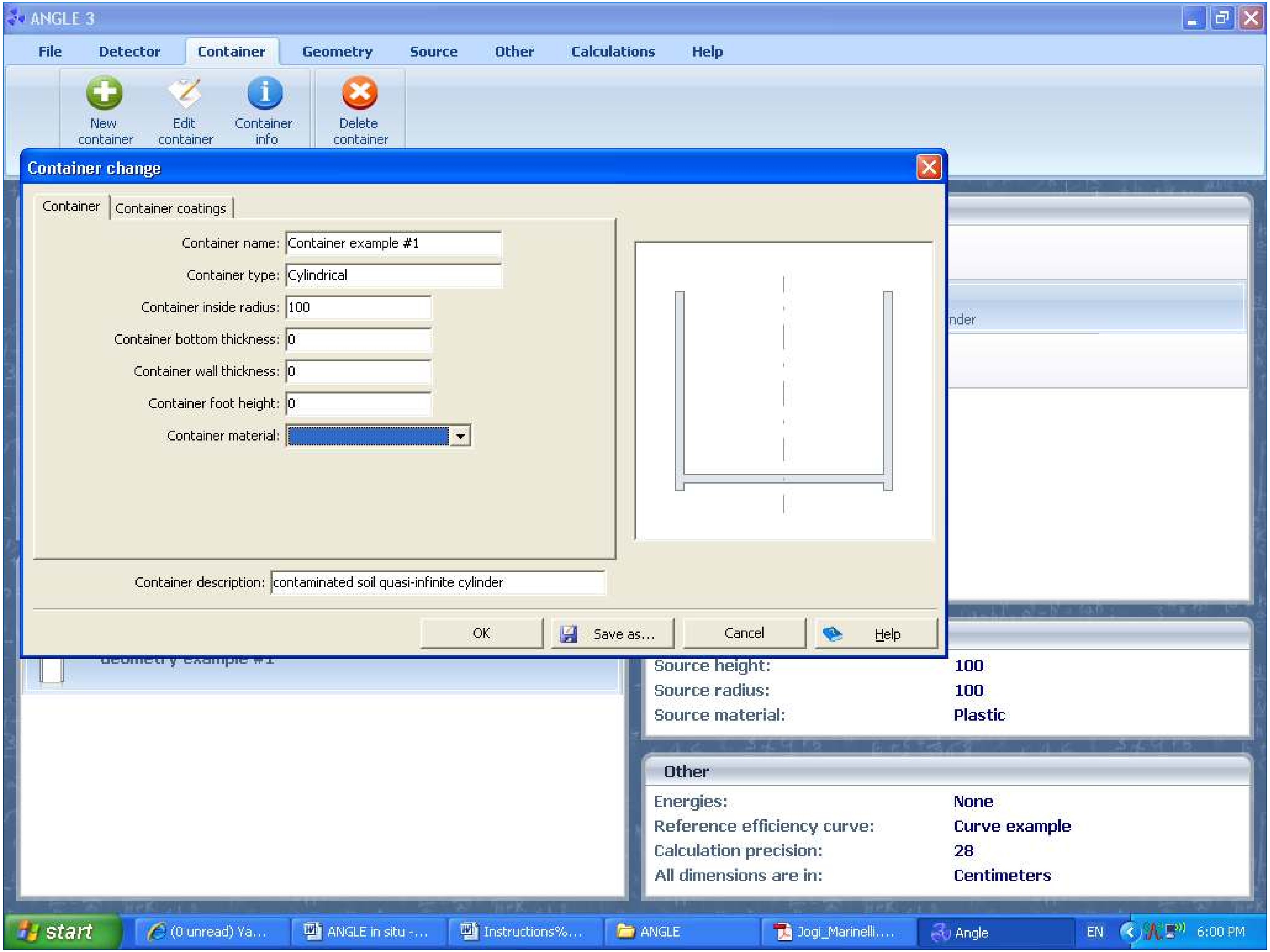
Soil
Detector

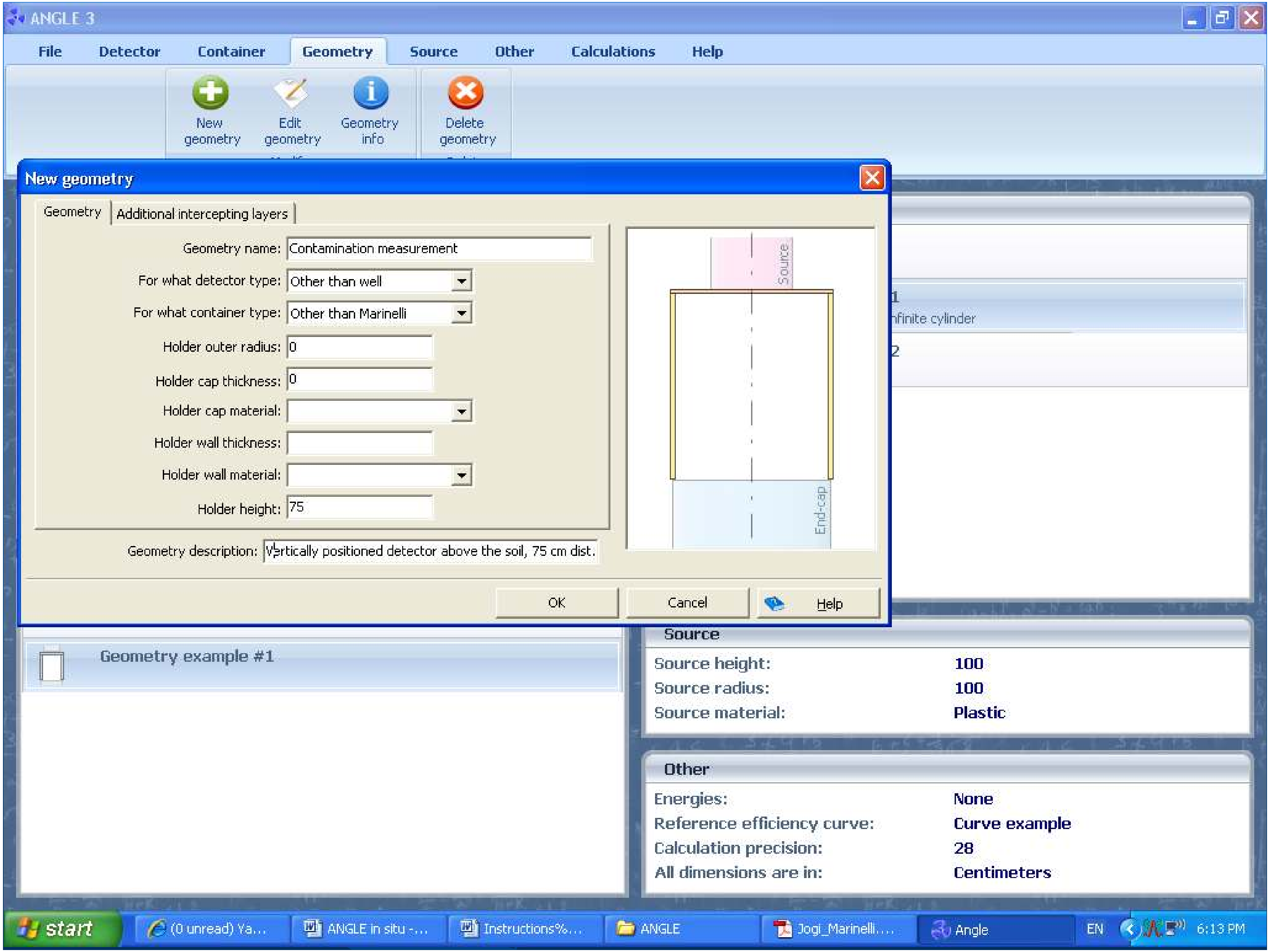
- **In case of surface contamination infinite soil surface can be approximated by a large, finite disc. When surface radioactivity migrates to within certain depth into the soil, slab geometry can be applied. This is, in effect, a large thin cylinder from ANGLE calculations standpoint.**

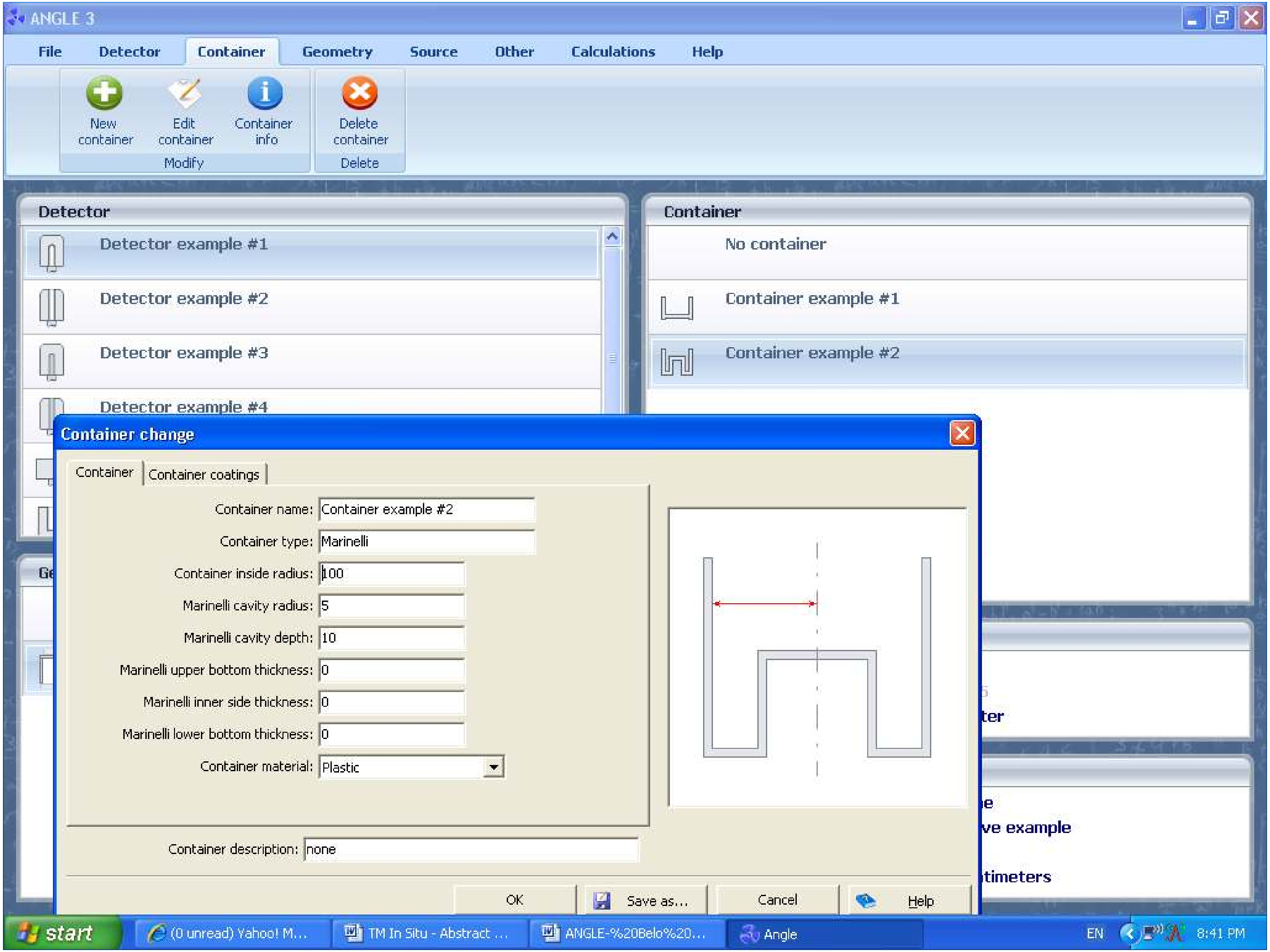
- **Note that previous example (surface contamination) is, in mathematical terms, a special case of this one**


Detector
Infinite soil slab


Detector
Finite soil slab


ANGLE 3
File
Detector
Container
Geometry
Source
Other
Calculations
Help
New container
Edit container
Container info
Delete container
Container change
Container
Container coatings
Container name: Container example #1
Container type: Cylindrical
Container inside radius: 100
Container bottom thickness: 0
Container wall thickness: 0
Container foot height: 0
Container material:
Container description: contaminated soil quasi-infinite cylinder
OK
Save as...
Cancel
Help
Source height: 100
Source radius: 100
Source material: Plastic
Other
Energies: None
Reference efficiency curve: Curve example
Calculation precision: 28
All dimensions are in: Centimeters
start
6:00 PM


ANGLE 3
File
Detector
Container
Geometry
Source
Other
Calculations
Help
New geometry
Edit geometry
Geometry info
Delete geometry
New geometry
Geometry
Additional intercepting layers
Geometry name:
Contamination measurement
For what detector type:
Other than well
For what container type:
Other than Marinelli
Holder outer radius:
0
Holder cap thickness:
0
Holder cap material:
Holder wall thickness:
Holder wall material:
Holder height:
75
Source
End-cap
Geometry description:
Vertically positioned detector above the soil, 75 cm dist.
OK
Cancel
Help
1
nfinite cylinder
2
Geometry example #1
Source
Source height:
100
Source radius:
100
Source material:
Plastic
Other
Energies:
None
Reference efficiency curve:
Curve example
Calculation precision:
28
All dimensions are in:
Centimeters
start
(0 unread) Ya...
ANGLE in situ -...
Instructions%...
ANGLE
Jogi_Marinelli....
Angle
EN
6:13 PM


ANGLE 3
File
Detector
Container
Geometry
Source
Other
Calculations
Help
New container
Edit container
Container info
Delete container
Modify
Delete
Detector
Detector example #1
Detector example #2
Detector example #3
Detector example #4
Container
No container
Container example #1
Container example #2
Container change
Container
Container coatings
Container name: Container example #2
Container type: Marinelli
Container inside radius: 100
Marinelli cavity radius: 5
Marinelli cavity depth: 10
Marinelli upper bottom thickness: 0
Marinelli inner side thickness: 0
Marinelli lower bottom thickness: 0
Container material: Plastic
Container description: none
OK
Save as...
Cancel
Help
start
(0 unread) Yahoo! M...
TM In Situ - Abstract ...
ANGLE-%20Belo%20...
Angle
EN
8:41 PM

Journal of Radioanalytical and Nuclear Chemistry, Vol. 257, No. 3 (2003) 551–555

Introduction of Marinelli effective solid angles for correcting the calibration of NaI(Tl) field gamma-ray spectrometry in TL/OSL dating

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A study is made of the corrections that are needed in the evaluation of the annual radiation dose, for use in TL/OSL-dating, via NaI(Tl) field gamma-ray spectrometry (monitoring of K, Th and U), calibrated via voluminous blocks that are simulating the Auger hole measuring conditions. Two cases are considered: the “Heidelberg” granite calibration block, which was found to be “quasi-infinite”, and the “Oxford” concrete calibration blocks, for which “effective” concentrations of elements are reported so as to account for their “non-infiniteness”. The calculations, via the software package ANGLE, are based on the concept of effective solid angles for Marinelli geometries.

Introduction

In the dating technique via thermally or optically stimulated luminescence,[1,2] the TL/OSL-age is given by:

$$\text{TL/OSL} - \text{age} = \frac{\text{TL/OSL} - \text{signal}}{\text{Annual radiation dose} \times \text{Sensitivity}} \quad (1)$$

$$[\text{conc}_{K,Th,U}]_{\text{field}} = [\text{conc}_{K,Th,U}]_{\text{block}} \times \frac{[\text{cps}_{K,Th,U}]_{\text{field}}}{[\text{cps}_{K,Th,U}]_{\text{block}}} \quad (2)$$

In the present work, this is investigated for the “Heidelberg” calibration block, for which it was thus far

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NUCLEAR INSTRUMENTS & METHODS IN PHYSICS RESEARCH
Section A

www.elsevier.com/locate/nima

Contribution of ^{210}Pb bremsstrahlung to the background of lead shielded gamma spectrometers

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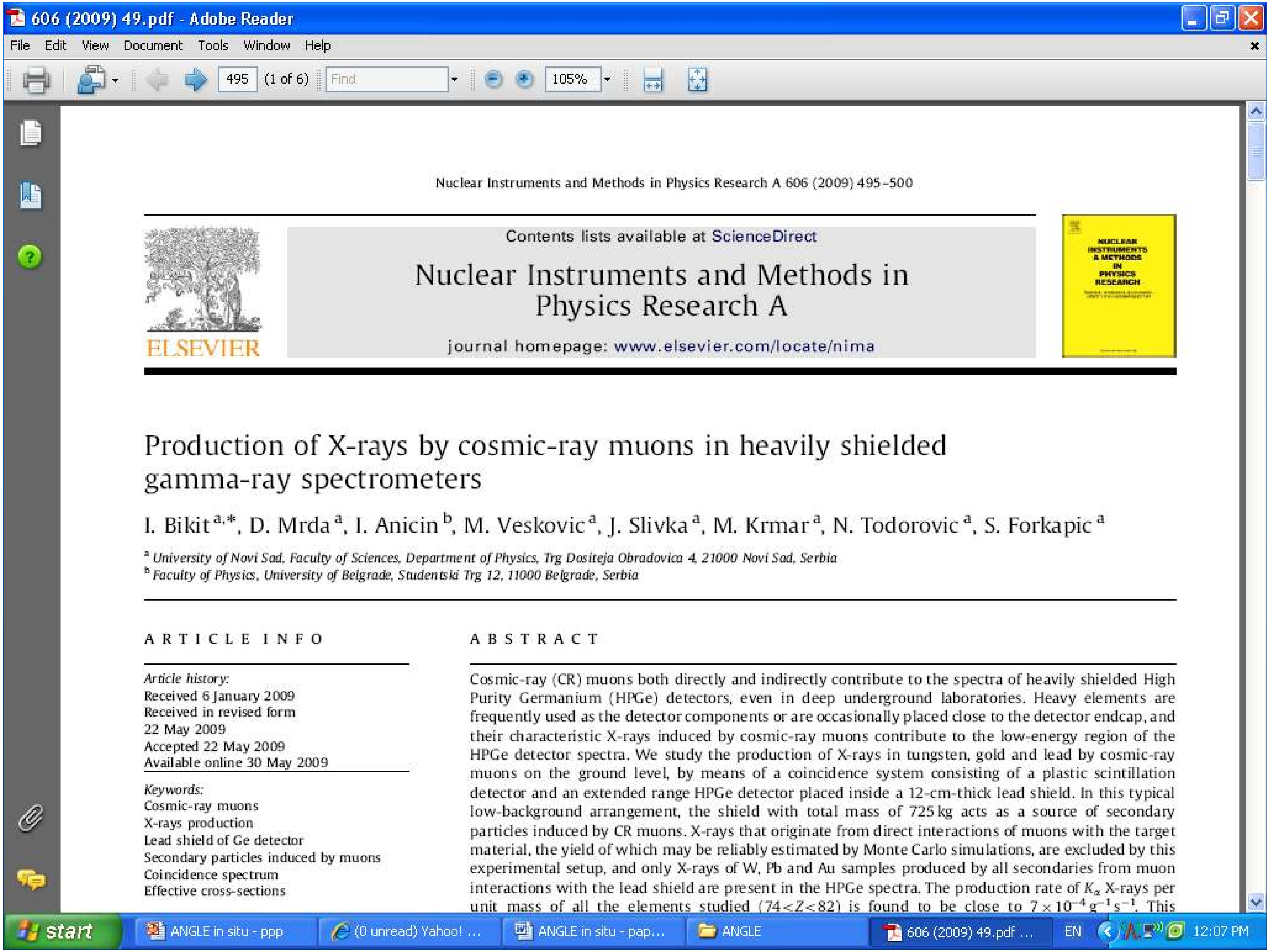
Abstract

Lead, which is often used as a shielding material, contains ^{210}Pb ($T_{1/2} = 22.3$ y). The 46.54 keV γ-intensity of ^{210}Pb can be easily reduced by an inner lining, but the bremsstrahlung caused by the β-decay of its daughter, ^{210}Bi, with a maximal electron energy of 1.16 MeV, will contribute to the gamma detector background. The spectrum of this bremsstrahlung is calculated by numerically fitting the β-spectrum and integrating the Koch–Motz formula. The absorption of the bremsstrahlung in the lead and detection efficiencies for the HPGe detector are calculated by the effective solid angle algorithm, using corrections for the photopeak/Compton ratio of cross-sections in Ge. By comparison with the measured background spectrum, it is shown that, for the lead with 25 Bq/kg of ^{210}Pb up to 500 keV of gamma spectrum, the bremsstrahlung contribution to the background is about 20% for our surface-based detector system. Also, we compared our calculations with a Monte Carlo simulation of another detector system with a shield containing 1 Bq/kg of ^{210}Pb and found that our analytical method gives a value of roughly two times higher than the Monte Carlo one for the total bremsstrahlung



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Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

Production of X-rays by cosmic-ray muons in heavily shielded gamma-ray spectrometers

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Cosmic-ray muons
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Lead shield of Ge detector
Secondary particles induced by muons
Coincidence spectrum
Effective cross-sections

A B S T R A C T

Cosmic-ray (CR) muons both directly and indirectly contribute to the spectra of heavily shielded High Purity Germanium (HPGe) detectors, even in deep underground laboratories. Heavy elements are frequently used as the detector components or are occasionally placed close to the detector endcap, and their characteristic X-rays induced by cosmic-ray muons contribute to the low-energy region of the HPGe detector spectra. We study the production of X-rays in tungsten, gold and lead by cosmic-ray muons on the ground level, by means of a coincidence system consisting of a plastic scintillation detector and an extended range HPGe detector placed inside a 12-cm-thick lead shield. In this typical low-background arrangement, the shield with total mass of 725 kg acts as a source of secondary particles induced by CR muons. X-rays that originate from direct interactions of muons with the target material, the yield of which may be reliably estimated by Monte Carlo simulations, are excluded by this experimental setup, and only X-rays of W, Pb and Au samples produced by all secondaries from muon interactions with the lead shield are present in the HPGe spectra. The production rate of K_α X-rays per unit mass of all the elements studied ($74<Z<82$) is found to be close to $7\times10^{-4}\,g^{-1}\,s^{-1}$. This

PERGAMON

Applied Radiation and Isotopes 56 (2002) 703–709

Applied Radiation and Isotopes

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Reliability of two calculation codes for efficiency calibrations of HPGe detectors

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Received 27 November 2000; received in revised form 15 November 2001; accepted 19 November 2001

Abstract

This paper reports the reliability of efficiency calibrations for γ-ray detectors using the calculation codes ANGLE and LabSOCS. For experimental verification, three HPGe detectors under various laboratory geometry configurations were used for this study. An overall comparison between experimental and calculated efficiency calibration curves is presented and comments on the various error sources affecting the final results are given. The deviations are generally below 10%, which could be acceptable for many applications.

Keywords: ANGLE code; LabSOCS code; Efficiency calibration codes; γ-ray spectrometry; HPGE detectors

Applied Radiation and Isotopes 68 (2010) 355–359

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Applied Radiation and Isotopes

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Testing efficiency transfer codes for equivalence

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[g] *Bucharest University, Bucharest, Romania*
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ABSTRACT

Four general Monte Carlo codes (GEANT3, PENELOPE, MCNP and EGS4) and five dedicated packages for efficiency determination in gamma-ray spectrometry (ANGLE, DETEFF, GESPECOR, ETNA and EFFTRAN) were checked for equivalence by applying them to the calculation of efficiency transfer (ET) factors for a set of well-defined sample parameters, detector parameters and energies typically encountered in environmental radioactivity measurements. The differences between the results of the different codes

ANGLE v2.1 paper NIM A.pdf - Adobe Reader

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Nuclear Instruments and Methods in Physics Research A ▮ (▮▮▮▮) ▮▮▮–▮▮▮

Contents lists available at ScienceDirect

Nuclear Instruments and Methods in Physics Research A

journal homepage: www.elsevier.com/locate/nima

ANGLE v2.1—New version of the computer code for semiconductor detector gamma-efficiency calculations

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Efficiency transfer method
Efficiency calibration
Semiconductor detectors
Gamma-spectrometry

ABSTRACT

New version of the commercially available ANGLE software for semiconductor detector gamma-efficiency calculations is presented. ANGLE allows for accurate determination of the activities of gamma spectroscopic samples for which no "replicate" standard exists, in terms of geometry and matrix. A semi-empirical ("efficiency transfer") approach is applied, based on the effective solid angle calculations. Advantages of both absolute (Monte Carlo) and relative (calibrated-source-based) methods are combined—while minimizing potential for systematic errors in the former and reducing practical limitations of the latter. ANGLE is broadly applicable, accounting for most of counting arrangements in gamma-spectrometry practice (in respect to detector types and configuration, source shapes and volumes, matrix composition, source-to-detector distance, etc.). Besides the years of practical utilization in many gamma-spectrometry laboratories, accuracy of the software is successfully tested in a recent IAEA-organized intercomparison exercise—ANGLE scored 0.65% average deviation from the exercise mean for $E_\gamma > 20$keV energies.

ANGLE v3.0

http://www.dlabac.com/angle/files/angle_setup.exe

http://www.ortec-online.com/software/angle.htm

bobo_jovanovic@yahoo.co.uk, adlabac@t-com.me

Thanks!


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