AMETEK®

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Optimizing the detector model to improve the overall quality of efficiency transfer calculations

NKS GammaRay X Webinar 2021

Marc Breidenbach
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AMETEK® ADVANCED MEASUREMENT TECHNOLOGY

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What to expect…and what not….

No

- ✓ new product introduction with fancy marketing literature
- ✓ finalized summary of an R&D project

But

- ✓ Description of a project that originated from customer feedback and ideas raised in scientfic papers (not ours)
- ✓ Short review of Efficiency Calibrations & Efficiency Transfer Calculations
- ✓ Ways to optimize Efficiency Transfer Calculations
- ✓ Presentation of EFFTRAN Optimizer - a new tool for Optimization of Detector Models (not released alpha test version)
- ✓ Outlook – plans for the future

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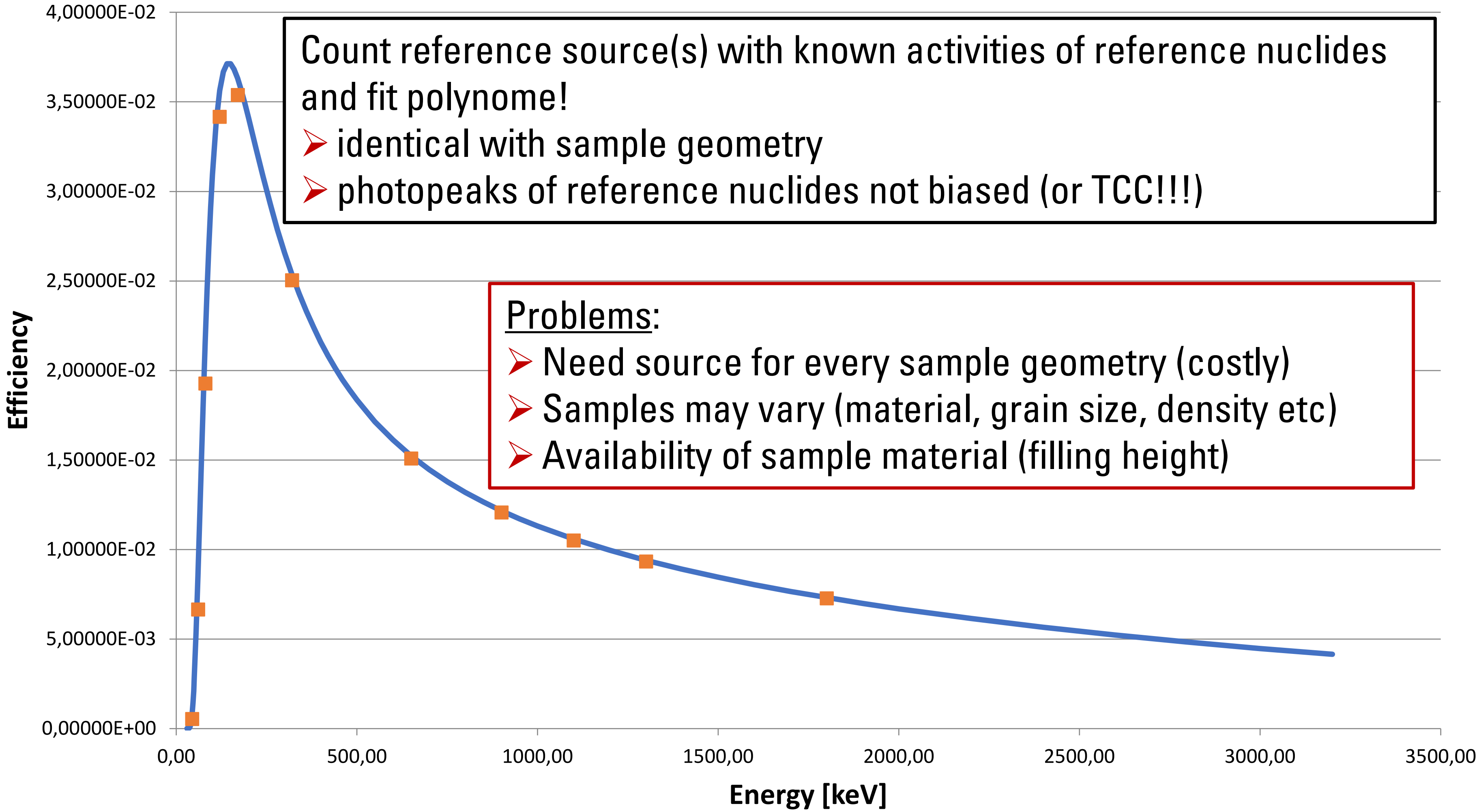
Efficiency Calibration



Count reference source(s) with known activities of reference nuclides and fit polynome!

- identical with sample geometry
- photopeaks of reference nuclides not biased (or TCC!!!)

Problems:

- Need source for every sample geometry (costly)
- Samples may vary (material, grain size, density etc)
- Availability of sample material (filling height)

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Efficiency Transfer

Mathematical Approach (Calculate the efficiency)

Efficiency Transfer (ANGLE, EFFTRAN, GESPECOR….)

Based on ideas of Moens et al, NIM 187(1981),451

$$\varepsilon_{smp} = \varepsilon_{ref} \frac{\eta_{smp}}{\eta_{ref}}$$

ε: full-energy-peak efficiency

- ✓ Compute a „virtual total efficiency“ η for sample and reference (basically something that is somewhow related to the efficiency).
- ✓ The ratio of these is then used as a correction to the experimentally determined efficiency of the reference (semi-empirical approach).
- ✓ Imperfections partially cancel out in the calculated ratio of the virtual efficiencies, since they are likely to be biased in the same direction for both the standard and the measured sample.

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EFFTRAN (MEFFTRAN)

By Tim Vidmar

Vidmar, T.,2005. EFFTRAN—a Monte Carlo efficiency transfer code for gamma-ray spectrometry. Nuclear Instruments and Methods A550,603–608.

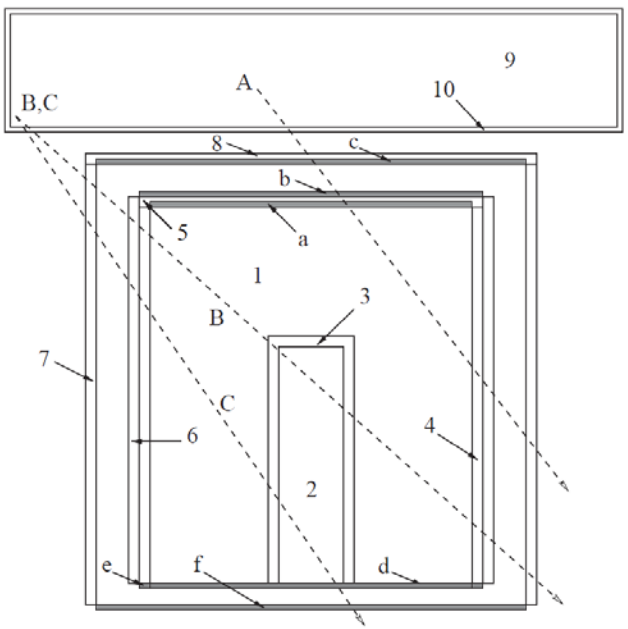

Fig. 1. The components of the model of the measurement setup: 1—HPGe crystal, 2—core, 3—inner dead layer, 4—side dead layer, 5—top dead layer, 6—crystal holder, 7—can, 8—window, 9—sample, 11—sample container, a,b,c,d,e,f—virtual volumes, shown filled (see text for explanation). The dimensions of individual volumes are not to scale. The space around the detector is assumed to be filled with air.

η: virtual **total** efficiency

$$\eta = \eta_{geo} \cdot \eta_{abs} = \frac{N_{detected}}{N_{total}}$$

η_{geo}: geometric efficiency/probability

(solid angle – how many of the emitted gammas are in direction to the detector)

η_{abs}: absorption efficiency/probability

(how many of the emitted gammas that reach the detector interact with it)

Virtual crystal absorption efficiency

$$\eta_{abs} = p_{trans,other} \cdot p_{abs,Ge}$$

$$= \prod_i e^{-\mu l_i} \cdot (1 - e^{-\mu l_{Ge}})$$

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EFFTRAN (MEFFTRAN)

- ✓ Very fast calculation <minute
- ✓ Free – register with Tim.Vidmar@sckcen.com and you get it
- ✓ Open source code
- ✓ Includes TrueCoincidenceSumming correction
- ✓ Easy to use through 3rd party sftw (-> LVis)
- ✓ Lots of scientific papers – well accepted in the European nuclear community
- ✓ Limited to cylinders, Marinellis, point sources (positioned centric on the detector)
- ✓ Only Excel GUI – Different modules for Marinelli (MEFFTRAN) or Well detectors
- ✓ Cannot be commercialized as is (XCOM package from NIST and KORDAT from PTB)

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Quality of Efficiency Transfer?

Several intercomparison studies published:

- ✓ Point source reference to extended samples (< 5 – 30%)
- ✓ Extended reference to extended sample with different geometry (typically < 15%)
- ✓ Extended reference to extended sample with same geometries but different composition/density or filling height (< 5 %)
- ✓ Usually better in higher energy range
- ✓ The closer sample and reference are, the better….
- ✓ My personal experience: Works very well when correcting for differences in sample volume or density (Proficiency tests; Intercomparisons). Not much feedback when using it for „sourceless calibration"…

What can be done to improve the quality?

Lépy, M-C., et al.,2001.Intercomparison of efficiency transfer software for gamma- ray spectrometry. Applied Radiation and Isotopes 55, 493–503.

Vidmar, et al., 2010. Testing efficiency transfer codes for equivalence. Applied Radiation and Isotopes 68, 355–359.
Vidmar, et al., 2010. Efficiency transfer between extended sources. Applied Radiation and Isotopes 68, 2352-2354.

H. Ramebäck, et al.,2021. Validation of EFFTRAN for efficiency transfer to distant geometries and volume sources. Journal of Radioanalytical and Nuclear Chemistry .

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Quality of Efficiency Transfer?

What can be done to improve transfer calculations?

- ✓ Improve the quality of the reference efficiency?

  Pay attention that the reference efficiency is corrected for (or unaffected by) true coincidence summing!

- ✓ Verify container/sample model. Use sample containers that are easy to describe in a model!

  Ideally cylinders with no curved bottom or edges. If not available adjust the container model such that a specific sample volume translates to the correct (measured) filling level. Use sample jigs to precisely position container (more important the smaller and closer to the detector the sample is). Use proper tools to reliably determine the filling height!

- ✓ Try to asses the true attenuation in the sample for better low energy performance.

  Sample material – elemental composition - usually unknown! Measure the transmission of a known source (Cutshall method). Bruggemann et al published a method that can be used as a direct input to EFFTRAN.

- ✓ Optimize the detector model

Cutshall, N.H.,et al.,1983. Direct analysis of 210Pb in sediment samples: self-absorption corrections. Nucl. Instrum. Methods 206, 309–312.

M. Bruggeman et al., 2016. Assessing sample attenuation parameters for use in low-energy efficiency transfer in gamma-ray spectrometry. Applied Radiation and Isotopes 109 547–550.

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Detector Model

QUALITY ASSURANCE DATA SHEET
GEM Series HPGe (High-Purity Germanium) Coaxial Detector System

Model and Serial Numbers

Detector Model No. GEM30-76
Cryostat Configuration CFG-SV-76
Dewar Model MOBIUS-ST-DET — Serial No. 59-P51889A
Preamplifier Model A257P — When calling Customer Service, always reference the Detector Serial No.
Preamplifier Serial No. 19164538
H. V. Filter Model 138EMI — Sales Order No. 25004493
H. V. Filter Serial No. 19079312
SMART-1-P Serial No.

Cryogenic Information

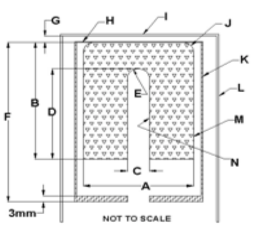
Dewar Capacity 28 liters — Static Holding Time
Detector Cool-Down Time 8 Hours

High Voltage Bias

Recommended Operating Bias POSITIVE 2700 Volts

Performance Specifications*

	Warranted	Measured	Amp Shape Time
Resolution (FWHM) at 1.33 MeV, ^{60}Co	1.85 keV	1.73 keV	6 µs
Peak-to-Compton Ratio, ^{60}Co	60:1	68:1	6 µs
Relative Efficiency at 1.33 MeV, ^{60}Co	30 %	35 %	6 µs
Peak Shape (FWTM/FWHM), ^{60}Co	1.9	1.9	6 µs
Peak Shape (FWFM/FWHM), ^{60}Co	2.6	2.6	6 µs
* FWFM/FWHM is typical, not warranted			
Resolution (FWHM) at 122 KeV, ^{57}Co	850 eV	706 eV	6 µs



E: NOMINAL 5-mm RADIUS
F: 105-mm CUP LENGTH
G: 4-mm SPACE
H: 0.03-mm/0.03-mm Al/Mylar
I: 1-mm Al
J: NOMINAL 8-mm RADIUS
K: 0.8-mm Al
L: 1-mm Al
M: 0.7-mm Ge/Li DEAD LAYER
N: 0.3-micron Ge/B DEAD LAYER

A= 57 mm Crystal Diameter
B= 66.1 mm Crystal Length
C= 8.3 mm Hole Diameter
D= 52.4 mm Hole Depth

OTHER Cryo: CFG-SV-76 # 17923

Data Certified By: DATE 28. Aug 19

Rev M

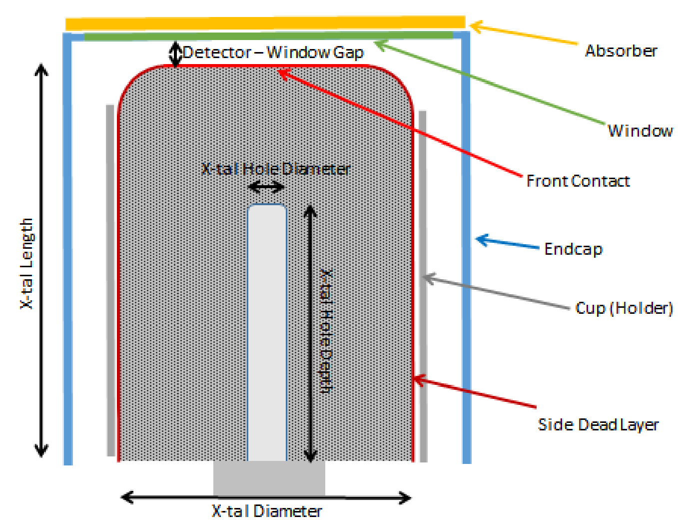
Dr. Elaine Roth (Director of Detector Technology):

…three largest sources of error, in order of largest to smallest, are as follows:

1. *Ge/Li dead layer, M*
2. *Radius of bulletization, J*
3. *Detector parameters (A, B, C, D)*

…

4. Top vacuum thickness



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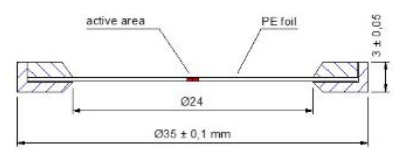
How to Optimize a Detector Model

- Count several references (eg point source in different distances– for container model only the distance could be a problem. Use jigs for precise positioning).
- Obtain calibrations for each distance (references).
- Use EFFTRAN to calculate the efficiency for each distance based on the references.
- Compare the calculated results with the „true“ values from the calibrations.
- Change the detector model (eg the contact thickness), calculate again and see if the results improve.
- Repeat and vary the detector parameters until an overall better transfer is achieved

Time consuming and prone for lots of errors



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Example

Relative deviation in % between computed and experimental efficiency for the detector model as given by the detector manufacturer:

Reference	Sample	59.5	88	122.1	165.9	661.7	898	1173.2	1332.5	1836.1	Average
Nigeria_0mm	Nigeria_25mm	7.557	12.486	8.643	7.527	3.678	6.077	5.684	6.942	10.079	
Nigeria_0mm	Nigeria_50mm	2.122	4.944	5.32	7.948	4.467	6.923	8.153	9.378	9.456	
Nigeria_0mm	Nigeria_125mm	7.323	1.93	0.189	6.155	6.723	8.999	10.132	9.101	8.724	
Nigeria_25mm	Nigeria_0mm	8.175	14.267	9.46	8.14	3.819	6.47	6.027	7.459	11.209	
Nigeria_25mm	Nigeria_50mm	5.88	8.618	3.637	0.455	0.819	0.901	2.617	2.618	0.692	
Nigeria_25mm	Nigeria_125mm	16.097	16.473	9.254	1.484	3.161	3.111	4.716	2.32	1.506	
Nigeria_50mm	Nigeria_0mm	2.168	5.201	5.619	8.634	4.676	7.438	8.877	10.349	10.444	5.686
Nigeria_50mm	Nigeria_25mm	5.553	7.934	3.51	0.457	0.826	0.909	2.688	2.689	0.687	
Nigeria_50mm	Nigeria_125mm	9.65	7.232	5.419	1.948	2.362	2.23	2.155	0.306	0.809	
Nigeria_125mm	Nigeria_0mm	6.824	1.894	0.189	6.558	7.207	9.888	11.275	10.012	9.558	
Nigeria_125mm	Nigeria_25mm	13.865	14.143	8.47	1.463	3.264	3.211	4.949	2.375	1.484	
Nigeria_125mm	Nigeria_50mm	8.801	6.744	5.141	1.911	2.419	2.281	2.203	0.305	0.802	

Housing endcap diameter	76.00
Housing endcap thickness	1.00
Crystal diameter	57.00
Crystal length	66.10
Crystal dead layer front	0.70
Crystal dead layer side	0.70
Housing window thickness	1.00
Housing window crystal distance	4.00
Crystal drilling diameter	8.30
Crystal drilling depth	52.40
Housing cup thickness	0.80
Crystal bullet radius	8.00
Absorber diameter	70.00
Absorber thickness	0.90

Detector

Type: Coax — Details

Model: GEM30-76

S/N: 59-P51889A

Add. info: Purchased October 2019
Recommended HV bias: 2700 V positive
CFG-SV in MOBIUS-ST-DET

NO OPTIMIZATION

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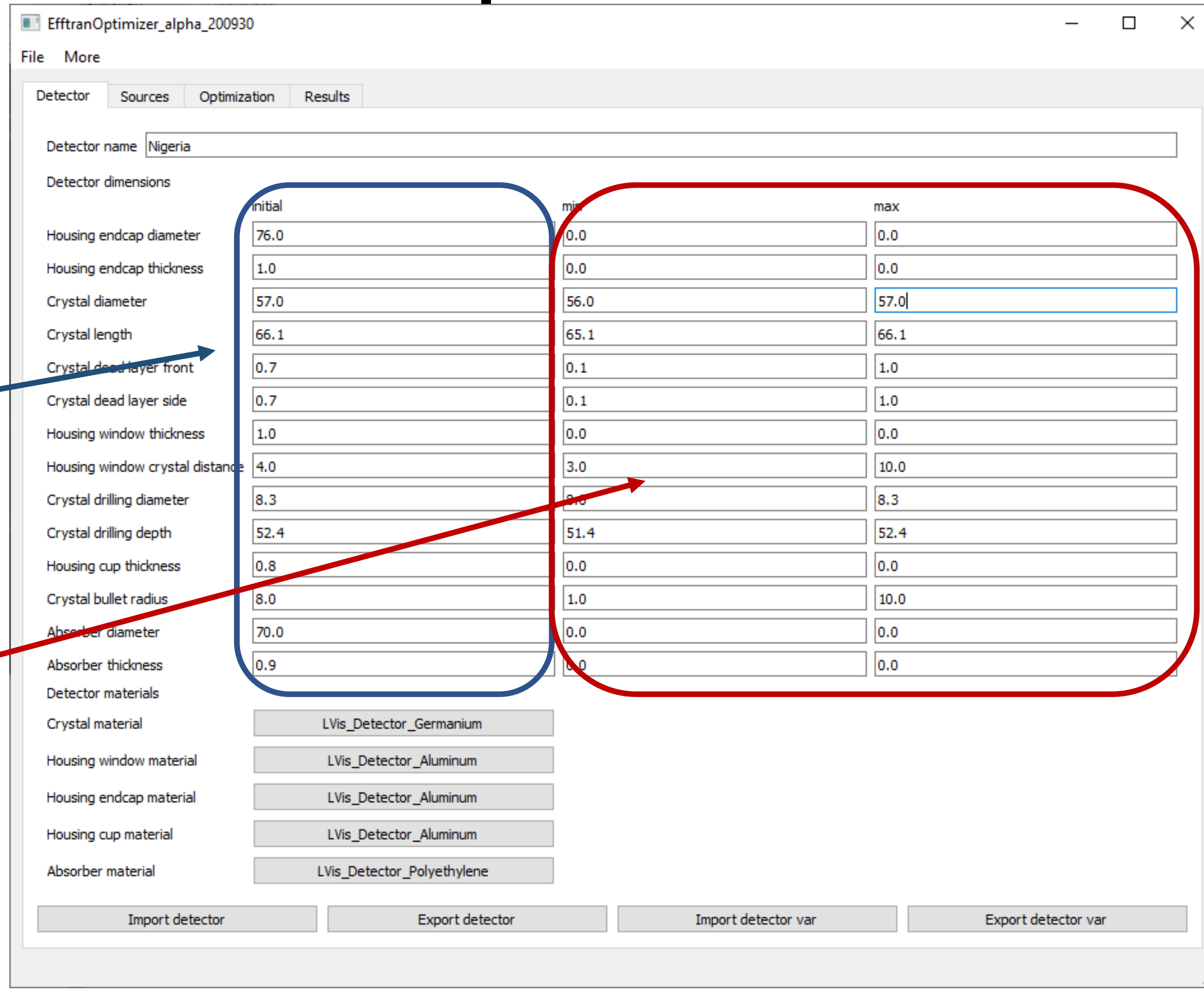
Solution: EFFTRAN Optimizer (by Dr. Felix Diel)

Detector sheet:

1. Enter the start parameters of the detector model using the data from the manufacturer (import from EFFTRAN possible).

2. Enter the dimensions that you want to vary by defining a min and max range



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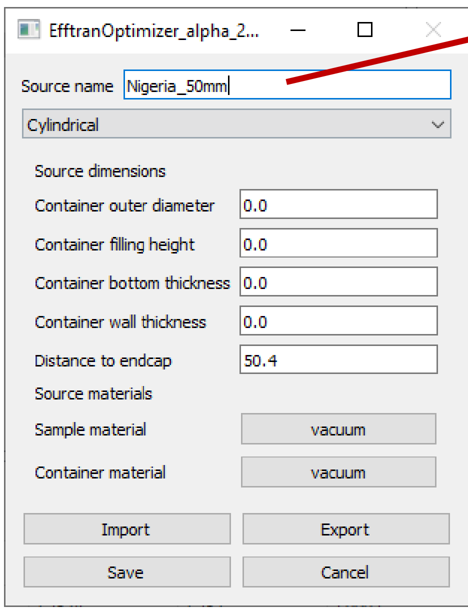
Solution: EFFTRAN Optimizer (by Dr. Felix Diel)

Sources sheet:

1. Describe the reference geometries (import from EFFTRAN possible).

2.



3. ly

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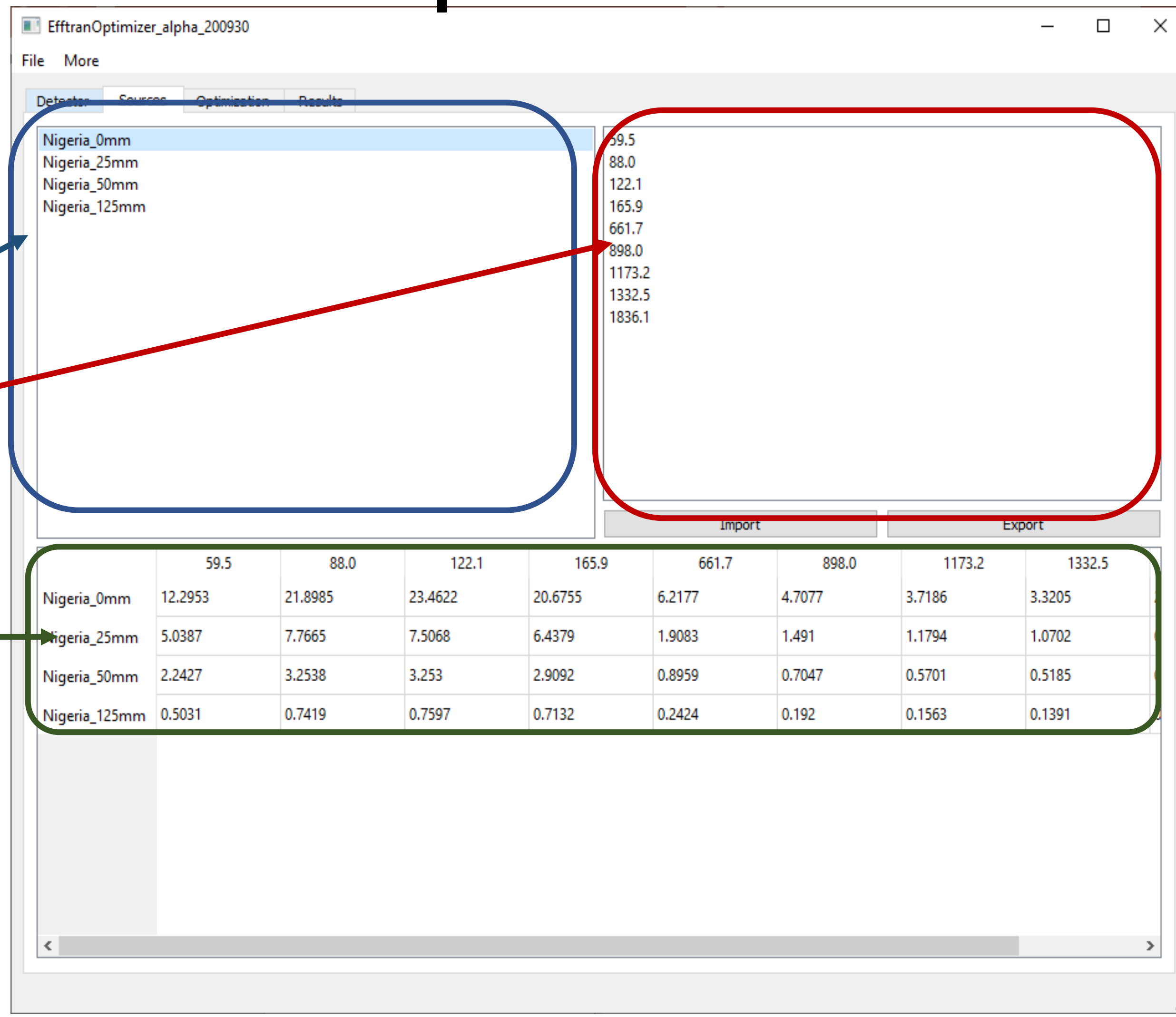

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Solution: EFFTRAN Optimizer (by Dr. Felix Diel)

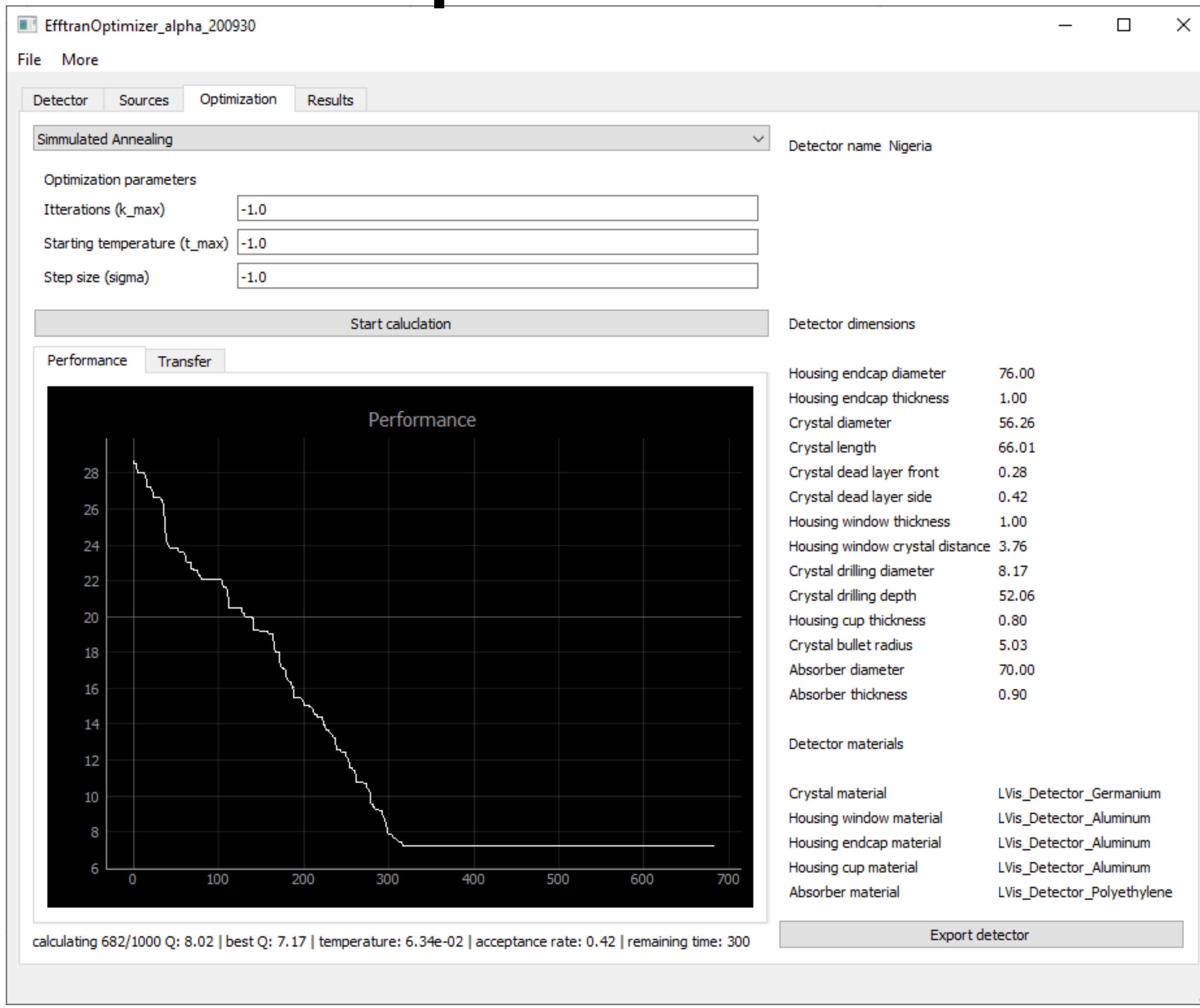
Optimization sheet:

1. Select optimization algorithm („Downhill Simplex“ or „Simulated Annealing“)

2. Start calculation

3. Optimizer will then trigger EFFTRAN and calculate the efficiencies for every geometry using the other geometries as references. A graph displays the max. deviation between the experimental and calculated efficiency for all transfers of a detector model. The current best detector model is shown.

4. Results can then be exported as a csv file.



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Solution: EFFTRAN Optimizer (by Dr. Felix Diel)

Relative deviation in % between computed and experimental efficiency:

Reference	Sample	59.5	88	122.1	165.9	661.7	898	1173.2	1332.5	1836.1	Average
Nigeria_0mm	Nigeria_25mm	0.004	1.818	1.92	1.904	3.753	0.935	1.168	0.266	3.798	2.012
Nigeria_0mm	Nigeria_50mm	0.153	2.185	3.198	0.55	3.353	0.539	0.918	2.3	2.51	
Nigeria_0mm	Nigeria_125mm	2.315	2.465	3.062	1.375	0.388	2.732	3.883	2.76	2.314	
Nigeria_25mm	Nigeria_0mm	0.004	1.852	1.884	1.869	3.617	0.926	1.154	0.267	3.948	
Nigeria_25mm	Nigeria_50mm	0.156	4.077	1.254	1.329	0.386	0.393	2.062	2.039	1.338	
Nigeria_25mm	Nigeria_125mm	2.319	4.362	1.121	3.218	3.991	3.633	4.993	2.5	1.542	
Nigeria_50mm	Nigeria_0mm	0.152	2.139	3.099	0.547	3.244	0.536	0.927	2.354	2.575	
Nigeria_50mm	Nigeria_25mm	0.156	3.918	1.238	1.347	0.387	0.394	2.105	2.081	1.32	
Nigeria_50mm	Nigeria_125mm	2.16	0.274	0.132	1.915	3.619	3.253	2.993	0.471	0.202	
Nigeria_125mm	Nigeria_0mm	2.263	2.406	2.971	1.394	0.39	2.808	4.04	2.838	2.369	
Nigeria_125mm	Nigeria_25mm	2.267	4.18	1.108	3.325	4.157	3.77	5.255	2.564	1.519	
Nigeria_125mm	Nigeria_50mm	2.114	0.273	0.132	1.952	3.755	3.362	3.085	0.473	0.201	

Housing endcap diameter	76.00
Housing endcap thickness	1.00
Crystal diameter	57.00
Crystal length	66.10
Crystal dead layer front	0.70
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Housing window thickness	1.00
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Crystal drilling diameter	8.30
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Housing cup thickness	0.80
Crystal bullet radius	8.00
Absorber diameter	70.00
Absorber thickness	0.90

Housing endcap diameter	76.00
Housing endcap thickness	1.00
Crystal diameter	56.85
Crystal length	65.94
Crystal dead layer front	0.52
Crystal dead layer side	0.50
Housing window thickness	1.00
Housing window crystal distance	6.00
Crystal drilling diameter	8.30
Crystal drilling depth	52.25
Housing cup thickness	0.80
Crystal bullet radius	1.83
Absorber diameter	70.00
Absorber thickness	0.90

OPTIMIZED Detector Model

(Optimized for EFFTRAN not necessary closer to reality!)

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Outlook

- ✓ Further test and validate the EFFTRAN Optimizer
  - more detectors
  - more geometries (point to extended, extended to extended)
  - Possible collaborations?
- ✓ Currently EFFTRAN Optimizer relies on TCS corrected references and the results are biased due to the fact that a change in the detector model results in a somewhat different TCC – we plan to implement not just efficiency transfer but TCS into the Optimizer.
- ✓ Possibly implement the EFFTRAN Optimizer into our software LVis
  - Just select your experimental calibrations and specify what detector parameters shall be optimized the rest is then done automatically.
- ✓ Current (limited) experience with optimized detector models indicate that they will - most likely - enable users to improve the quality of efficiency transfer calculations especially when reference and sample deviate significantly

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Thank You!

Any Questions?

If you have interest in LVis and how to use it with EFFTRAN please contact me or our local country representatives for a web or on-site demo!

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