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UncertRadio: Software for determining characteristic limits in accordance to DIN EN ISO 11929 for radioactivity measurements

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Summary

In Germany, radioactive substances in the environment are monitored in accordance with the Treaty establishing the European Atomic Energy Community (EURATOM) of 1957 and the German Radiation Protection Act (Bundesrepublik Deutschland, 2017). The evaluation of radiometric measurements requires the estimation of associated uncertainties as defined in the ISO GUM (Joint Committee for Guides in Metrology, 2008b). In addition, German law requires that the `characteristic limits` (decision threshold (DT) and the detection limit (DL)) are determined on the basis of this uncertainty in accordance with ISO 11929-1-3:2025 (2025a, 2025b, 2025c) to ISO 11929-4:2022 (2022).

Statement of need

To the best of the authors' knowledge, `UncertRadio` is the only publicly available software to determine the `characteristic limits` in a user-centralized way. `UncertRadio` can be used for a variety of applications from alpha, beta and gamma radiation measurements including dosimetry for up to three radionuclides simultaneously. Therefore, it is especially suited for modern liquid scintillation measurement procedures of e. g. strontium isotopes. The user only needs to define the evaluation model by providing a set of equations in text-form to calculate the output quantity value. The required partial derivatives are calculated internally.

There are two main analytical approaches used within the software:

- Direcly analyseable procedures: The basic evaluation model is linear in the net count rate. Thus, the output value can be calculated directly (Kanisch, 2016a).
- Procedures utilizing linear unfolding methods: The model additionally includes linear least squares procedures for fitting e. g. time-dependent decay or build-up curves (Kanisch, 2016b).

Additionally, the model can be evaluated with a Monte Carlo simulation following ISO 11929-2 (2025b) (see Figure 1). This represents the method of propagating whole distributions, which has advantages if the distributions of the input variables significantly deviate from the normal distribution; see ISO GUM Supplements 1 (2008a) and 2 (2011).

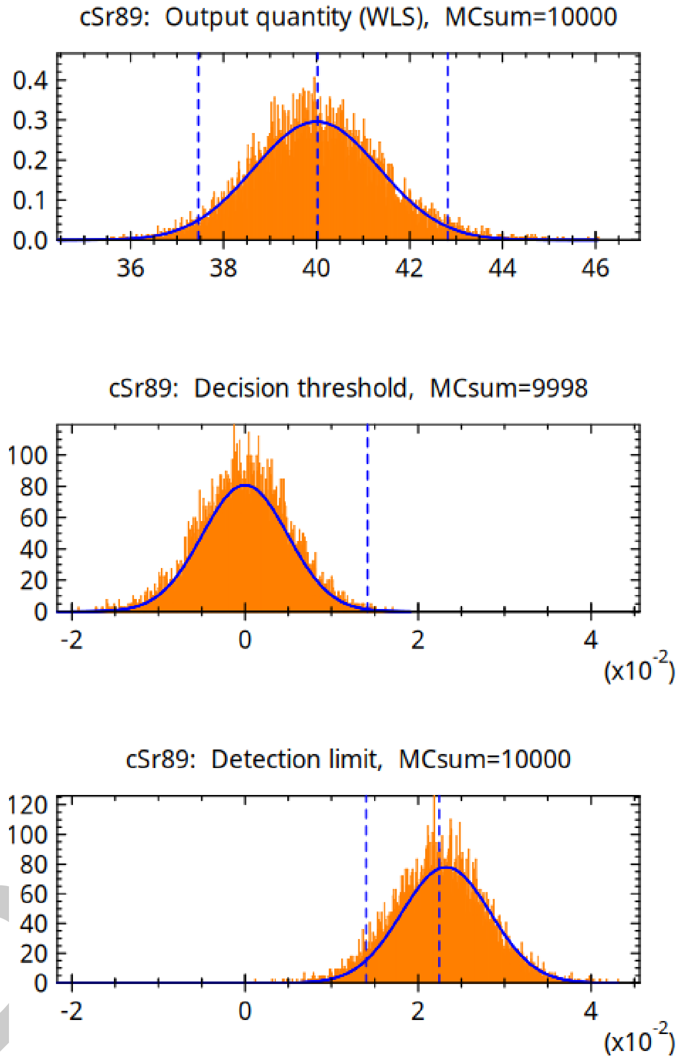

Figure 1: Example of results obtained with the Monte Carlo simulation using weighted linear least squares (WLS) in accordance with ISO 11929-2:2025 (International Organization for Standardization, 2025b). The three displayed distributions refer, top-down, to the output quantity, the decision threshold, and the detection limit. The curves shown in blue represent the Gaussians calculated analytically (2025a). The vertical dashed lines indicate the lower and upper limits of the coverage interval, with the mean value shown between them (upper graph); the decision threshold (middle graph); and both the decision threshold and detection limit (lower graph).

Scientific references

`UncertRadio` has been used in several scientific publications. It is referenced by the standard ISO 11929-1-3:2025 (2025a, 2025b, 2025c) to ISO 11929-4:2022 (2022) and actively used by the German authorities for monitoring environmental radioactivity and external radiation.

In Kanisch (2016a), an overview of directly analyzable procedures is presented. Two significant linear relationships in the model equations for the net count rate (common in evaluation models) were identified providing a generalized approach for the determination of the characteristic limits. Kanisch (2016b) extends the evaluation models to include linear unfolding methods utilizing a weighted linear least-squares (WLS) approach for the first stage of the model. This step is solved using matrix-algebra which also takes parameters with uncertainties in the design matrix into account.

Software design

UncertRadio is written in modern Fortran utilizing many Fortran 2003 and 2008 features, e. g. the C-interoperability. The graphical user interface (GUI) is built with GTK 3 in combination with gtk-fortran (Magnin et al., 2019), which provides the required Fortran bindings. PLplot is implemented for the graphical presentations (Alan W. Irwin et al., 2019).

Many of the utilized numerical procedures are derived from the work of Miller (2004), Burkardt (2024) and Brandt (1999). A Fortran function parser (Schmehl, 2008) is included for interpreting user-defined equations.

The project utilizes a CMake-based build system that automatically detects required dependencies, and produces both stand-alone Windows binaries and Linux builds. Continuous integration is handled by GitHub Actions workflows, which compile the code on Linux and Windows, run the included tests and publish the built artifacts (for Windows). This ensures reproducible builds and enables rapid verification of every commit.

The documentation is built with Sphinx (*Sphinx Documentation*, 2025) from reStructuredText sources and is publicly hosted on the project's GitHub Pages site.

Applications, examples and quality control

UncertRadio includes a set of approximately 70 example projects, which are structured text files available in both English and German languages. They are mostly based on real-world applications but also cover the examples in ISO 11929-4 (2022). These examples illustrate the structure of the set of equations for various measurement models. A short overview of all example projects is given in section 2.5 of the UncertRadio documentation. These examples contributed to the validation of UncertRadio. To verify if UncertRadio is working correctly, all examples can be run automatically by selecting "Options/QC batch test" in the main menu. Since Version 2.6 this can also be done in the terminal by running:

```
./UncertRadio run_tests
```

Should an error occur, the authors would be grateful for any reports submitted via the GitHub issues page.

Availability and documentation

UncertRadio is available free for download as compiled Windows binaries since 2014.

Recently, it was decided to publish the source code as open source software under the GNU General Public License 3. The UncertRadio source code is available on GitHub. Detailed building instructions are provided within the README file. UncertRadio works both on Linux and Windows and comes with language packages for English, French and German. Nevertheless, only Windows binaries are currently provided for download. They are available on GitHub and on the homepage of the Thünen-Institute.

Until Version 2.5.3 UncertRadio contained an extensive compiled HTML help (chm) documentation for the description of the program features in German and English languages. However, since Version 2.6 it has been replaced by a modern Python Sphinx (*Sphinx Documentation*, 2025) based documentation, but is lacking some German translations. Thus, the old chm version is still available in the repository or upon request. The individual help topics are available from within UncertRadio using various help buttons. In addition, the

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complete documentation is available on GitHub Pages. The current development goals and open issues can be found in the README file.

Code problems can be reported in the issues tab on GitHub. The authors offer to help within their capabilities. Feedback and contributions via pull request are greatly appreciated.

Conflict of interest

The authors declare no financial conflicts of interest.

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