**ICRS10-RPS2004**
Madeira, 9-14 may 2004- 21st Century Challenges in Radiation Protection and Shielding
To be published in regular issue of *Radiation Protection Dosimetry*

# Γ-DOSE: a User-Friendly Module for Dosimetry and Shielding Calculations

J. Galy, V. Berthou, J. Magill
*European Commission, Joint Research Centre, Institute for Transuranium Elements, Postfach 2340, 76125 Karlsruhe, Germany*

## ABSTRACT

An interactive multimedia tool, ***Nuclides.net***, has been developed at the Institute for Transuranium Elements. The Nuclides.net "integrated environment" is a suite of computer programs ranging from a powerful user-friendly interface, which allows the user to navigate the nuclides chart and explore the properties of nuclides, to various computational modules. Among them, the Γ-DOSE dosimetry and shielding module allows the user to calculate gamma dose rates from point sources of single nuclide and mixtures. The user can alternatively obtain a dose rate through a given shield material and thickness, or a shield thickness of material required to obtain a given dose. More than 3000 nuclides are available in the Nuclides.net database for dosimetry calculation. In addition, the user has a choice of 10 shield materials. Detailed description of this module and some potential applications are presented in the present paper.

**ICRS10-RPS2004**
Madeira, 9-14 may 2004- 21st Century Challenges in Radiation Protection and Shielding
To be published in regular issue of *Radiation Protection Dosimetry*

# Γ-DOSE: a User-Friendly Module for Dosimetry and Shielding Calculations

J. Galy, V. Berthou, J. Magill
*European Commission, Joint Research Centre, Institute for Transuranium Elements, Postfach 2340, 76125 Karlsruhe, Germany*

## INTRODUCTION

An interactive multimedia tool, *Nuclides.net* [1] has been developed at the Institute for Transuranium Elements. *Nuclides.net* applications run over the internet on a web server. The user interface to these applications is via a web browser. Information submitted by the user is sent to the appropriate applications resident on the web server. The results of the calculations are returned to the user, again via the browser. The product is aimed at both students and professionals for reference data on radionuclides and computations based on this data using the latest internet technology. It is particularly suitable in the nuclear industry, health physics and radiation protection, nuclear and radiochemistry, nuclear physics, astrophysics, etc. In this paper we describe in details one of the main modules in Nuclides.net, i.e. the dosimetry and shielding module – Γ-DOSE.

## THE Γ-DOSE MODULE

### Description

This module allows the user to calculate gamma dose rates from point sources of single nuclide and nuclides mixtures through a choice of 10 different shield media. All known gamma lines and emission probabilities for the nuclide(s) are accounted in the calculation. Over 3000 nuclides with more than 70000 gamma lines from the JEF2.2 datafile are in the database.

### Interface

The main interface, shown in Fig. 1 allows the users to select the source strength, the source/detector distance, the shield material and material thickness in a user friendly interface. The source strength can be set in different units, namely Activity (Bq), Activity (Ci), Mass (g) or number of atoms. In addition, the user has the choice of 10 shield materials: lead, concrete (dry), tin, tungsten, uranium, water, aluminum, air (dry air at sea level) and tissue.

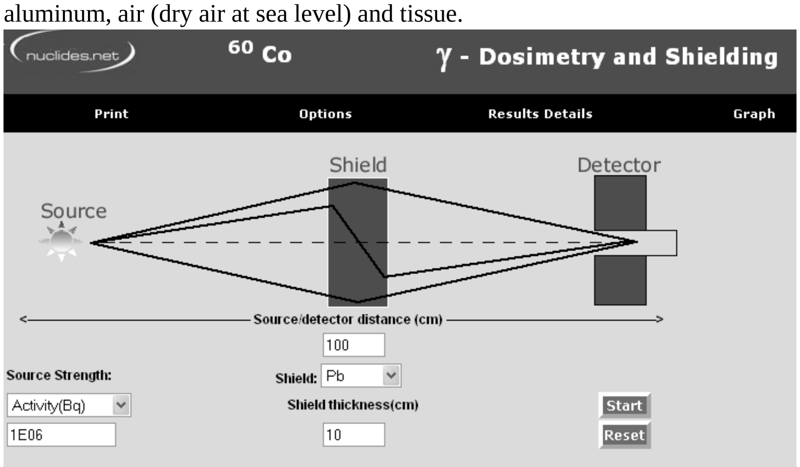


**Fig. 1.** The main user interface in the Γ-DOSE program.

### Options

There are two modes of operation. The user can obtain a dose rate through a given shield material and thickness. Alternatively, the thickness of shield material required to obtain a given dose rate can be calculated. The user can choose to include only gammas, X-rays, or both in the calculations. In addition, the threshold energy for contributions to the dose rate can be set by the user. The default value is 15 keV – photons with lower energy are absorbed by the outer layers of human tissue (see example 1).

### Results

The calculation is performed by pressing the start button on the main window leading to a result window shown in Fig.2. In addition to the calculated dose rate, subsidiary results are presented: the half-value layer (HVL) and the tenth value layer (TVL) thicknesses required to reduce the gamma dose rate to 50% and 10% respectively of the initial value, and the specific gamma dose rate constant for the given nuclide.

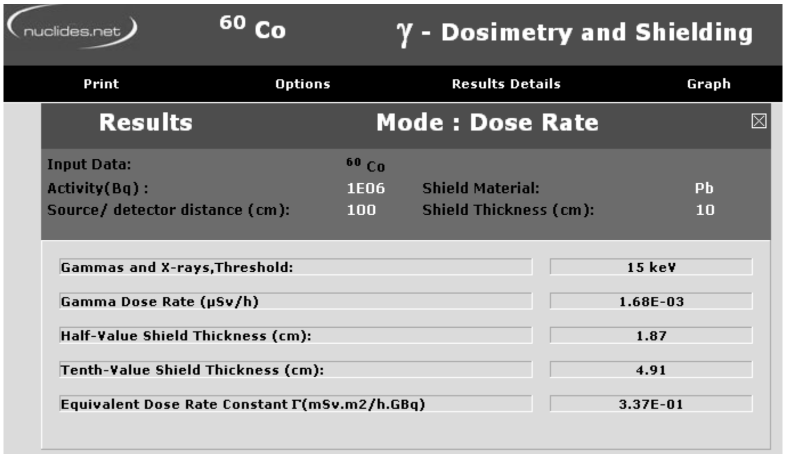


**Fig 2.** Results window of a dose rate calculation of 1 MBq of $^{60}$Co at 1 metre distance with 10 cm of lead shielding in front of the detector.

Details of the calculation can be accessed through a "Results Details" button. This leads to a spreadsheet window with detailed information of the calculations (e.g. the energies, the corresponding emission probabilities, the mass attenuation coefficients, the B factors, the mass absorption coefficients, etc.). An example is shown in Fig.3.

## EXAMPLES OF APPLICATIONS

### Example 1: Threshold energy in dosimetry calculations - Radiation hazard of analytical X-Ray system

Analytical x-ray systems produce highly intense x-rays which are predominantly low in energy relative to those utilized in medical diagnosis and therapy. Such x-rays are often described as being "soft" because of the ease by which they are absorbed in matter. While this characteristic enables soft x-rays to be readily shielded (generally requiring only a few millimeters of lead), it also makes them particularly hazardous since they are highly absorbed even by soft tissue.

For example, 10 keV x-rays will deposit 40 percent of their energy in the first millimeter of tissue. This can be illustrated with the Γ-DOSE module in Nuclides.net as follows.

As a first step, one searches the database for X-rays with an energy range from 5 to 20 keV. We find two suitable nuclides for the illustration: $^{52}$Ti with a half-life of 1.7 min and an X-ray at 5.4 keV and, in addition, a gamma-line at 17 keV and $^{64}$Ge (half-life: 1.06 min) with an X-ray at 10.3 keV.

We can then calculate the dose rate attenuation in different skin thicknesses to illustrate the absorption of these low energy radiations by the skin. The results are given in the table 1. From this table we can note that 5 keV X-rays will deposit half of their energy in the first ¼ millimeter of the epidermis, while for 10 keV it needs 1 mm.

**TABLE 1**. X-ray absorption in the skin. Values are given in percent.

| | Skin thickness (mm) | | | | | |
|---|---|---|---|---|---|---|
| Energy (keV) | 0.1 | 0.25 | 0.5 | 0.75 | 1 | 10 |
| 5.4 | 29.6 | 58.3 | 82.6 | 92.8 | 97.0 | 100.0 |
| 10.3 | 5.0 | 12.4 | 23.0 | 32.3 | 40.7 | 99.5 |
| 17 | 1.4 | 3.2 | 6.3 | 9.4 | 12.4 | 73.2 |

Based on these observations, it can be concluded that low energy X-rays do not contribute to the "whole body" dose. For this reason the threshold energy is set, by default, to 15 keV. On the other hand, the energy deposited by x-rays as they interact with matter may result in the breaking of chemical bonds. When the X-rays irradiate living tissue, such chemical changes may result in altered structure or function of constituent cells. Thus, hazard effects may be manifested at the level of the skin.

### Example 2: Nuclide mixtures and radiation shielding – Considerations for the construction of a hot-cell

The aim of this example is to demonstrate a shielding calculation with a mixture of nuclides, and to show the module working in the "shield thickness" mode.

The Hot-Cell provides facilities for performing operations of highly radioactive material with minimal radiation exposure to the personnel involved. In most of the equipped institutes, the hot cells are designed to accept fuel rods for post irradiation investigations. To protect the user against the gamma radiation, the different cells are shielded with lead bricks and can be operated through a lead glass window.

The German regulations give a limit for occupationally exposed workers (category A) of 20 mSv/ year assuming 2000 working hours (2000 h of exposure). This means that the limit is 10 µSv/h for a regular worker working with a hot cell. The limit for occupationally exposed workers (category B) is 6 mSv/year assuming 2000 working hours (2000 h of exposure). This means 3 µSv/h. This limit has to be taken into account in the design of the hot cell.

**TABLE 2**. Main fission products in 1 ton of spent. Main actinides are not shown since they do not have a significant influence in the total dose rate.

| Nuclide | Half-life | Activity (Bq) | Mass (g) |
|---|---|---|---|
| $^{134}$Cs | 2.07 y | $1.47 \cdot 10^{15}$ | 30.89 |
| $^{137}$Cs | 30.09 y | $1.73 \cdot 10^{15}$ | 539 |
| $^{90}$Sr | 28.86 y | $3.43 \cdot 10^{15}$ | 673.3 |
| $^{90}$Y | 2.67 d | $1.67 \cdot 10^{14}$ | 0.1689 |
| $^{125}$Sb | 2.76 y | $1.47 \cdot 10^{15}$ | 4.355 |
| $^{147}$Pm | 2.63 y | $1.05 \cdot 10^{15}$ | 30.6 |
| $^{106}$Ru | 1.02 y | $4.54 \cdot 10^{14}$ | 3.722 |
| $^{154}$Eu | 8.6 y | $3.39 \cdot 10^{14}$ | 33.98 |
| $^{85}$Kr | 10.76 y | $3.37 \cdot 10^{14}$ | 23.32 |
| $^{144}$Ce | 280 d | $2.43 \cdot 10^{14}$ | 2.059 |

For this study we create a nuclide mixture using the Virtual Nuclide module in Nuclides.net based on ORIGEN calculations taking into account the 11 main actinides and 10 fission products from a spent fuel rod 4.2% enriched from a standard PWR reactor (50GWd/t ) and after 6 years of cooling [2]. The main fission products are given in table 2 for 1 ton of spent fuel. Fig. 3 shows the detailed results of the dose rate from 500 g of non-shielded fuel.

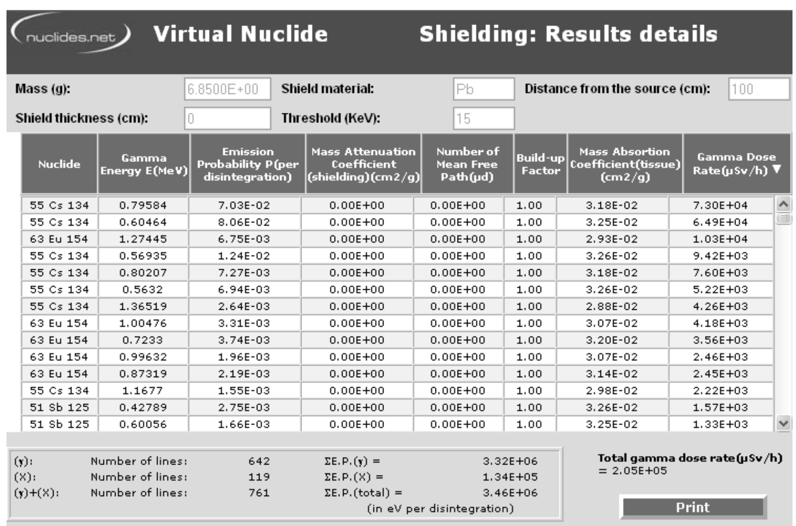


**Fig. 3**. Detailed results of a dose calculation of 6.85 g of the transuranium elements and fission products corresponding to a 500g spent fuel. The calculation without shielding shows the main contributors to the dose rate (e.g. $^{134}$Cs and $^{154}$Eu). When no shielding material is given, the B factor is 1.

We can then run the Γ-DOSE module and using the "shield thickness" mode calculate the thickness of lead required to obtain 3 µSv/h at 1 m of distance. The calculation gives a result thickness of 16.3 cm.

In most of the existing hot cells, reinforced concrete walls are the main shielding used for construction. The Γ-DOSE module makes available dry concrete to use as a shielding; one can use it as a crude approximation. The calculation gives a required thickness of 94.8 cm of concrete. Typically, hot-cells have wall thickness of approximately 1 m of reinforced concrete and 1 m thick lead glass window.

**Example 3: Long-range attenuation and multiple scattering effects – Dispersion of a concealed source of $^{60}$Co**

We consider a source of $^{60}$Co concealed somewhere in the centre of a city. Since the radioactivity is not dispersed, population exposure occurs only through external radiation. As a source of $^{60}$Co, we consider a capsule (used in radiotherapy) containing 1.7 g corresponding to an activity of $7.4\text{x}10^{13}$ Bq (2000 Ci). The dose rate at the distance r from the source in air is given by

$$D(r) = (kA/r^2)\cdot B(r)\cdot e^{-(\mu/\rho)\rho r}$$

where k is the specific gamma dose rate constant, A is the activity of the source, B(r) is the build-up factor, $\mu/\rho$ the mass attenuation coefficient and $\rho$ the density of air. The gamma dose rate at various distances from the concealed source is calculated with the Γ-Dose module in Nuclides.net. Figure 4 shows the dose rate as function of distance from the source for three types of calculations: in “vacuum" (no absorption by air, no scattering), in air (absorption, no scattering), and in air (absorption and scattering). At 1 m from source the γ-dose rate is 24.9 Sv/h. At 1.23 km from the source the dose rate reaches the value of 1 mSv/year (or 0.11 μSv/h), the limit for members of the public. These results take into account the attenuation by air and the build-up factor.
Such a concealed radioactive source in an area of high population density could lead to a significant radiation exposure to a large number of people. On the assumption that radiation effects are directly proportional to the radiation dose without threshold, then the sum of all doses to all exposed individuals is the collective effective dose, CD, given by $\sum_i D(r_i)\cdot\rho_p\cdot\pi r_i\cdot\Delta r_i\cdot\Delta t$, where $\rho_p$ is the population density, and Δt the exposure time.
For the above source (2000 Ci of $^{60}Co$), an exposure time of 2 hours and a population density of 2600 inh/km$^2$, CD = 4.2 man·Sv. Neglecting air attenuation and multiple scattering, the collective dose has a higher value of CD = 7.8 man·Sv. More importantly, results show that the exposed area is strongly dependent on the attenuation and scattering in air. Accounting for these effects, the exposed area decreases from 15 km to 1.23 km.

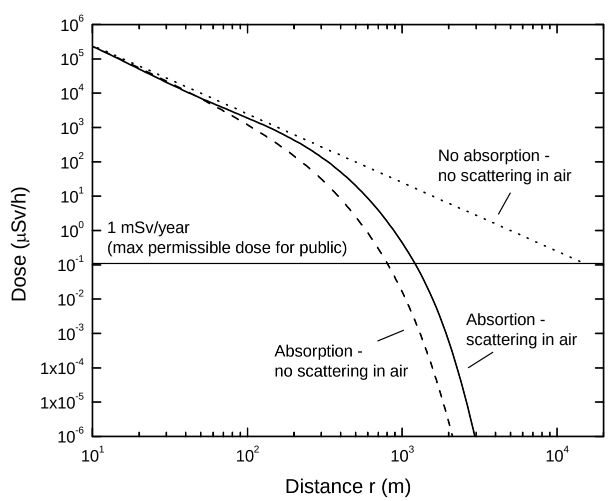


**Fig.4**: Long-range radiological effects of a $^{60}Co$ source ($7.4\text{x}10^{13}$ Bq). Beyond 100 m, the results show clearly the importance of accounting for air attenuation and scattering in the dose rate calculations

## CONCLUSION

The Γ-DOSE module of the software package Nuclides.net is a versatile tool for quick and accurate dosimetry and shielding calculations. It allows the user to calculate gamma dose rates from point sources of single nuclide and mixtures, through a choice of 10 different shield media. Over 3000 nuclides with more than 70000 gamma lines from the JEF2.2 datafile are in the database. Examples given highlight the main characteristics of the module.

## REFERENCES

[1]. J. Magill, Nuclides.net · An Integrated Environment for Computations on Radionuclides and their Radiation, Springer Verlag, ISBN 3-540-43448-8 (2003). See www.nuclides.net
[2]. J. Magill et al. “Impact Limits of Partitioning and Transmutation Scenarios on Radiotoxicity of Actinides in Radioactive Waste” , Nuclear Energy, 2003, **42**, No.5,Oct., 263-27