

## **Nuclides.net: A Computational Environment for Nuclear Data and Applications in Radioprotection and Radioecology**

V. Berthou, J. Galy, J. Magill\*, K. Lützenkirchen

*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 for decay calculations, dosimetry and shielding calculations, etc. The product is particularly suitable for environmental radioprotection and radioecology.

### **1. Introduction**

The interactive multimedia tool, *Nuclides.net* [1] has been developed at the Institute for Transuranium Elements. 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. More than 3000 nuclides are available in the Nuclides.net database as well as more than 70,000 gamma lines and emission probabilities. Among the large amount of data available, the user can access the effective dose coefficients for the inhalation and ingestion, taken from the ICRP72. The two main modules in Nuclides.net, the *dosimetry and shielding* module and the *decay* module, are described in this paper. The decay module allows the user to calculate the mass, activity or radiotoxicity of a given isotope and his daughter product after a certain period of decay. The  $\Gamma$ -DOSE dosimetry and shielding module allows the user to calculate gamma dose rates from point sources of single nuclide and mixtures. In addition, the user has a choice of 10 shield materials. Two examples of application are presented in this paper.

### **2. Description of Nuclides.net**

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 Nuclide Explorer is an interface that allows the user to navigate through the nuclide chart. Data are available on 3650 ground states and isomers and these data are from internationally recognized sources. The "Data Sheets" module shows basic data on the selected nuclide, such as the mass, half-life, abundance, spin and parity, decay mode, branching ratios, daughters, and radiotoxicity. Additional windows contain spectral information. More than 70,000 gamma lines and emission probabilities are available. The "Fact Sheets" module gives important properties derived from the basic data, such as heat, neutron, and gamma emission rates, information on radiotoxicity and nuclide transportation.

.

\* Corresponding author

Among the modules, the “Decay Engine” module provides exact solutions to the differential equation for the radioactive decay of nuclides. In the main interface “Full Decay” the user can select the source strength (mass, activity or numbers of atoms) and the time at which the evaluation is required. The result of the calculation lists the parents and daughters, the number of atoms, their masses, activities, gamma emission rates and gamma dose rates. The choice of output quantities can be selected in the option windows, where, in addition, ingestion and inhalation radiotoxicities, spontaneous fission rate, etc can be computed.

The "Dosimetry and Shielding" module allows the calculation of gamma dose rates from both unshielded and shielded point sources. All known gamma lines and emission probabilities are accounted in the calculation. Alternatively, calculations of the required shielding thickness for a given source and a desired resulting dose rate can be also performed. A choice of 10 shield materials is available. The main interface allows the user to select the source strength, the source/detector distance, the shield material and thickness. The output of the calculations include the gamma dose rate (or shield thickness), the half and tenth value thickness of shield material and the specific gamma dose rate constant.

Finally, the "Fission Yield" module gives the user access to fission products and yields for 36 fissioning nuclides (data for spontaneous fission and neutron induced fission with thermal, fast, and 14 MeV neutrons) from the main international datafiles.

Calculations can be computed for single nuclide but also for a mixture of nuclides via the “Virtual Nuclide” module.

### 3. Examples of Application

#### 3.1. French Atomic Tests in Mururoa

Between 1966 and 1996, France conducted 193 nuclear tests above and beneath the atolls of Mururoa and Fangataufa in French Polynesia, Pacific, with a total release of 10.3 Mtons TNT for the atmospheric tests and 3.1 Mtons TNT for the underground tests [2,3]. We can estimate in a simple way the activity released by the atmospheric tests by evaluating the activity of the remaining plutonium and the activity of the main fission products.

The energy release is equivalent to  $4.3 \times 10^{16}$  J. Knowing that each fission produces  $3.2 \times 10^{11}$  J, we can estimate that  $1.3 \times 10^{27}$  atoms (535 kg) of  $^{239}\text{Pu}$  have fissioned. Assuming that 20% of  $^{239}\text{Pu}$  have fissioned, we can estimate that 2140 kg of plutonium remains after the tests.

In order to know the main fission products, we use the fission yield module of Nuclides.net. After selecting  $^{239}\text{Pu}$ , we select to the fission yield interface. Several libraries can be chosen, as well as 3 different excitation energies, thermal, fast and 14 MeV. In the case of a fission bomb, fast neutrons are used. The result of the calculation is shown in Figure 1. There are over 1000 fission products grouped into pages. The data for each fission product consists of the half-life, the independent fission yield (IND), the error in IND, the cumulative fission yield (CUMUL) and the error in CUMUL. The fission product listed can be re-arranged by clicking on the header label. The main fission products are  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ , with a cumulative yield of, respectively,  $6.5 \times 10^{-2}$  and  $2 \times 10^{-2}$ . Therefore the quantity of  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$  produced by the French atmospheric tests in Mururoa is, respectively,  $8.8 \times 10^{27}$  atoms and  $2.8 \times 10^{27}$  atoms.

In order to estimate the activity released by the remaining plutonium and the two main fission products, we use the decay module of Nuclides.net. First the  $^{239}\text{Pu}$  is selected and the decay module interface opened (Figure 2). As an input the quantity must be chosen in number of atoms. As we simply want an instantaneous activity, no time needs to be selected. The decay module can be used as a unit converter: by changing the unit from number of atoms to Becquerel, we obtain the instantaneous activity arising from the amount of  $^{239}\text{Pu}$  remaining, i.e.

$4.9 \times 10^{15}$  Bq. The same calculation can be made with  $^{137}\text{Cs}$  and  $^{90}\text{Sr}$ . The results are shown in Table 1. The total activity released is estimated to  $9 \times 10^{16}$  Bq.

### 3.2. Radiological Dispersal Device

Radiological Dispersal Devices (RDD), also called “dirty bombs”, employ conventional explosives in order to disperse radioactive material. Radioactive sources used for various medical and industrial applications, such as cancer treatment, medical diagnostics, food sterilization, smoke detectors, if not properly secured, could be employed for the construction of RDDs [4,5].  $^{60}\text{Co}$ , most common radioisotope used in radiotherapy, could be used in an RDD. A capsule of  $^{60}\text{Co}$  used for cancer treatment typically contains about 2000 Curie ( $7.4 \cdot 10^{13}$  Bq), i.e. about 1.7 grams. Two scenarios are described: a concealed source in a city centre, and a dirty bomb explosion, both made with a capsule of  $^{60}\text{Co}$ .

#### 3.2.1. External exposure due to a concealed source

In this scenario we consider a source of  $^{60}\text{Co}$  located, for example, in the centre of a city. Since the radioactivity is not dispersed, population exposure occurs only through external radiation. The gamma dose rate at various distances from the source is calculated with the Dosimetry and Shielding module of Nuclides.net.  $^{60}\text{Co}$  is selected in the Nuclide Explorer, and the  $\Gamma$ -dose module interface opened. As an input, the source strength (a mass of 1.7 g in this example) is chosen, the source detector distance (100 cm as a first step), the shield (air in its case), and the shield thickness (here the thickness is equal to the distance source/detector) are taken. The output is shown in Figure 3. At 1 m from source the  $\Gamma$ -dose rate is 24.9 Sv/h. In order to find the necessary distance to receive a dose lower to 1 mSv/y, the option “shield thickness” must be selected in the  $\Gamma$ -dose interface. At 1.23 km from the source the equivalent dose rate reaches the value of 1 mSv/year (or  $0.11 \mu\text{Sv/h}$ ), the limit for members of the public. Figure 4 shows the map of the area around the concealed source. These results take into account the attenuation by air and the build-up factor. The gamma dose rate at various distances from the source is shown again in Figure 5 but results are also shown where absorption and/or scattering in air are neglected. The results show clearly the importance of these absorption and scattering effects over distances of the order of 1 km. It is clear that the exposed area is strongly dependent on the attenuation and scattering in air. Accounting for these effects, the radius of the exposed area decreases from 15 km to 1.23 km.

#### 3.2.1. Internal exposure due to inhalation after an RDD explosion

In this scenario, it is assumed that the RDD has been dispersed uniformly in fine aerosol form resulting in a radioactive cloud of  $^{60}\text{Co}$  spread over a cylindrical region of radius  $R = 1000$  m and height  $h = 20$  m. It is further assumed that the density of the dispersed gas in this region is constant. The committed effective dose  $E(50)$  (dose generated by inhaled radioactive material within the next 50 years) due to internal exposure during a period of 2 hours is calculated. This committed effective is expressed by:

$$E(50)_{\text{inh}} = e(50)_{\text{inh}} \cdot A_V \cdot R_{\text{inh}} \cdot \Delta t$$

Where  $e(50)_{\text{inh}}$  is the effective dose coefficient,  $A_V$  the activity per volume,  $R_{\text{inh}}$  the breathing rate of the exposed person ( $1.2 \text{ m}^3/\text{h}$ ),  $\Delta t$  the time of exposure.

The only unknown parameter is the effective dose coefficient for  $^{60}\text{Co}$  which can be found in Nuclides.net Data Sheets module (see Figure 6). The value of  $e(50)_{\text{inh}}$  is  $2.9 \times 10^{-8}$  Sv/Bq. And therefore the committed effective dose is 82 mSv.

#### 4. Conclusion

*Nuclides.net* is an integrated environment for computations on radionuclides and their radiation. The "integrated environment" is a suite of computer programs ranging from a powerful user-friendly interface, which allows the user to navigate the nuclide chart and explore the properties of nuclides, to various computational modules for decay calculations, dosimetry and shielding calculations. Studies of the French Atomic Tests in Mururoa and the Radiological Dispersal Devices have been described, showing the large application field of the Nuclides.net software applied to environmental radioprotection.

#### 5. References

- [1] J. Magill, "Nuclides.net - An Integrated Environment for Computations on Radionuclides and their Radiation", Springer Verlag, (2003). For further information, see the Nuclides.net website at <http://www.nuclides.net>.
- [2] "Radiological situation at the atolls of Mururoa and Fangataufa: Main Report (Radiological assessment reports series)", IAEA, 1998.
- [3] E.T. Brown, "The consequences of underground nuclear testing in French Polynesia", ATSE Focus, No.104, Nov/Dec 1998. <http://www.atse.org.au/publications/focus/focus-brown-et.htm>
- [4] C. D. Ferguson, T. Kazi, and J. Perera, *Commercial Radioactive Sources*, Center for Nonproliferation Studies, Monterey Institute of International Studies, Monterey, USA, Occasional Paper Nr. 11, 2003. <http://cns.miiis.edu/pubs/opapers/op11/op11.pdf>
- [5] The DOE/NRC Interagency Working Group, Radiological Dispersion Devices, Report to the Nuclear Regulatory Commission and the Secretary of State, May 2003. [http://www.energy.gov/engine/doe/files/dynamic/1222004142719\\_RDDRPTF14MAY03.pdf](http://www.energy.gov/engine/doe/files/dynamic/1222004142719_RDDRPTF14MAY03.pdf)

Figure and Tables



Figure 1: Fission yield module for the <sup>239</sup>Pu fission with fast neutrons

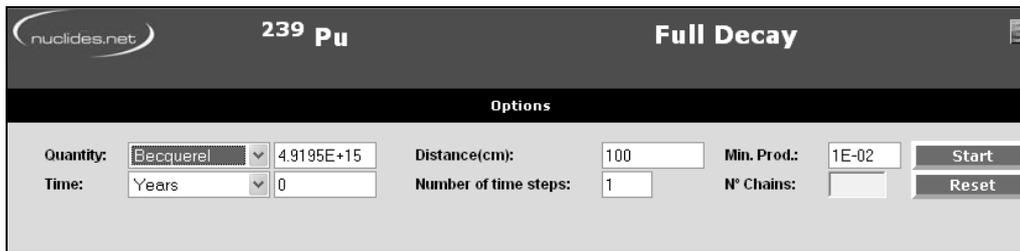


Figure 2: Decay module for <sup>239</sup>Pu

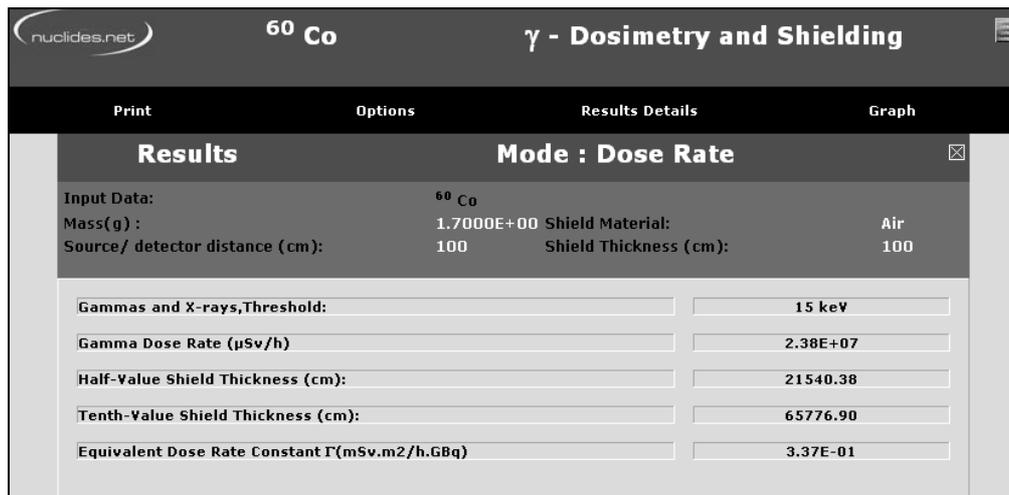


Figure 3: Γ-dose module output for 1.7 g of <sup>60</sup>Co in air at 1 m from the detector

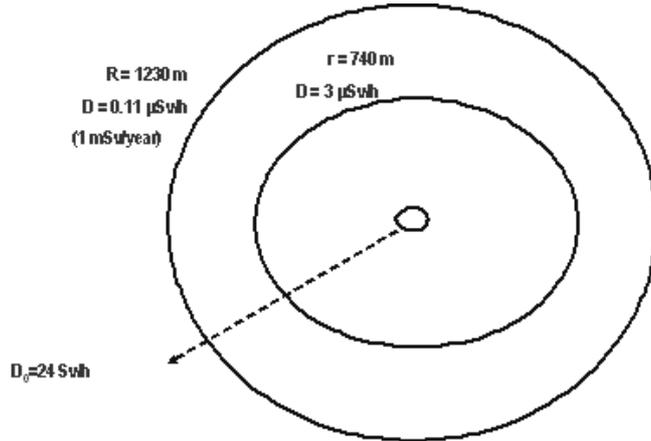


Figure 4: Map of the area around a concealed source of 1.7 g of <sup>60</sup>Co

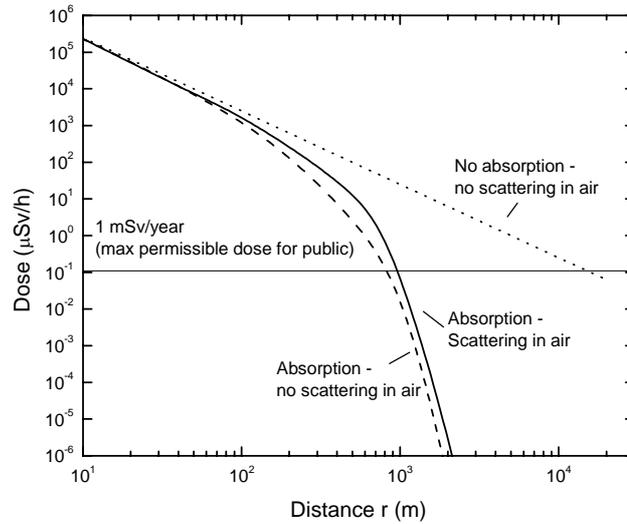


Figure 5: Long-range radiological effects of a <sup>60</sup>Co source ( $7.4 \times 10^{13}$  Bq).

Print		FactSheets		Notes		Averaged Cross sections	
<b>Mass Excess</b>	-61644.2 (± 14) keV	<b>Mass</b>	59.933822160 (± 1503) u	<b>Half-life</b>	5.2714 (± 5) y	<b>Abundance</b>	-
<b>Spin</b>	5	<b>Parity</b>	+	<b>Binding Energy</b>	8.747 MeV		
<b>Type of decay</b>	β-	<b>Branching ratio</b>	1.00E+00	<b>Decay Energy, Q(MeV)</b>	2.82	<b>Daughters</b>	28 Ni 60
<b>Mean Decay Energies</b>		<b>Alpha(MeV)</b>	0	<b>Electron(keV)</b>	96.6	<b>Photon(keV)</b>	2504
<b>Effective Dose Coefficient Ingestion (Sv/Bq)</b>	3.4000E-09	<b>Effective Dose Coefficient Inhalation (Sv/Bq)</b>	2.900E-08	<b>Reference Annual Dose Workers</b>	20 mSv	<b>Reference Annual Dose Public</b>	1 mSv

Figure 6: Data Sheets for <sup>60</sup>Co

**INSIUME 2004**

Albena, Bulgaria, 27-30<sup>th</sup> September 2004 – International Symposium on Environmental Radioprotection and Radioecology  
To be published in regular issue of *Journal of Environmental Radioactivity*

Isotope	Number of atoms	Activity (Bq)
<sup>239</sup> Pu	$5.4 \times 10^{27}$	$4.9 \times 10^{15}$
<sup>137</sup> Cs	$8.8 \times 10^{25}$	$6.4 \times 10^{16}$
<sup>90</sup> Sr	$2.8 \times 10^{25}$	$2.1 \times 10^{16}$
Total	-	$9.0 \times 10^{16}$

Table 1: Release of activity from the French atomic tests in Mururoa