WOLFRAM VIRTUAL
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Workers Exposed for a Long Time to Random Radioactive Aerosols

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ABSTRACT

A model of the human body tracking the path of uranium from intake to excretion (via urine and feces) has been developed. It has been applied to workers exposed to radioactive aerosols. These workers are typically subjected to periodic internal contamination assessments through bioassays, such as whole-body or partial-body monitoring and excreta sample measurements. By fitting human models to bioassay measurements, the radioactive intake of the workers can be estimated. Static Air Samplers (SAS), if available, can also be used to reduce uncertainties in the estimation. The model takes into account that intakes are random and there are periods without exposure (e.g., weekends,

holidays). This method has been applied to workers exposed over long periods. A Mathematica package has been used to facilitate friendly estimation, and it has been integrated into a webMathematica toolbox called BIOKMOD (http://oed.usal.es/webMathematica/Biokmod/).

Here is presented a summarized description of the method

The problem: Estimate doses and intake in workers exposed to UO2 radioactive aerosols

- Method 1.- Uranium concentration , C_i(t), is measured using air control in different places P_i. Worker are moving in the area.

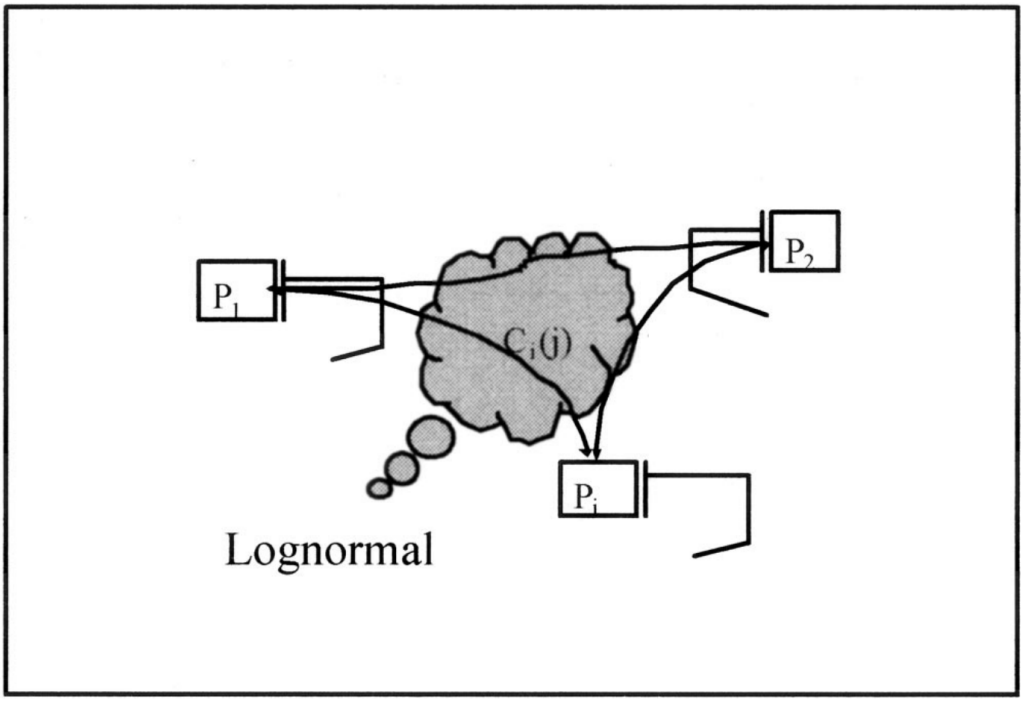


Fig. 1. Worker moving in an area with air samplers fixed at points P_i. The daily concentration $C_i(j)$ at point i on day j can be fitted to a log-normal distribution.

The problem: This method has very big uncertainties.

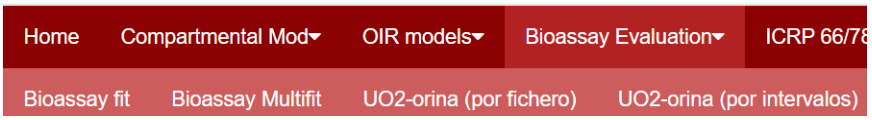
- Method 2.-Taken periodically urine samples and computing the daily uranium excretion: $\{t_d, m_d, u_d\}$
  The problem: The uranium distribution in the human body should be modeled taken into account that the intake are ramdon.

For a best estimation of the uranium intake by the workers we have developed a method taking into account both kind of measurements

> Sánchez-León Guillermo.; López M.A.; Moraleda M.; Rodríguez-Díaz Juan M.: "Bioassays in workers exposed to long time random intakes" Radiation and Applied Radiation and Isotopes (180) 2022. (https://doi.org/10.1016/j.apradiso.2021.110057)

A friendly application using the WL is applied.

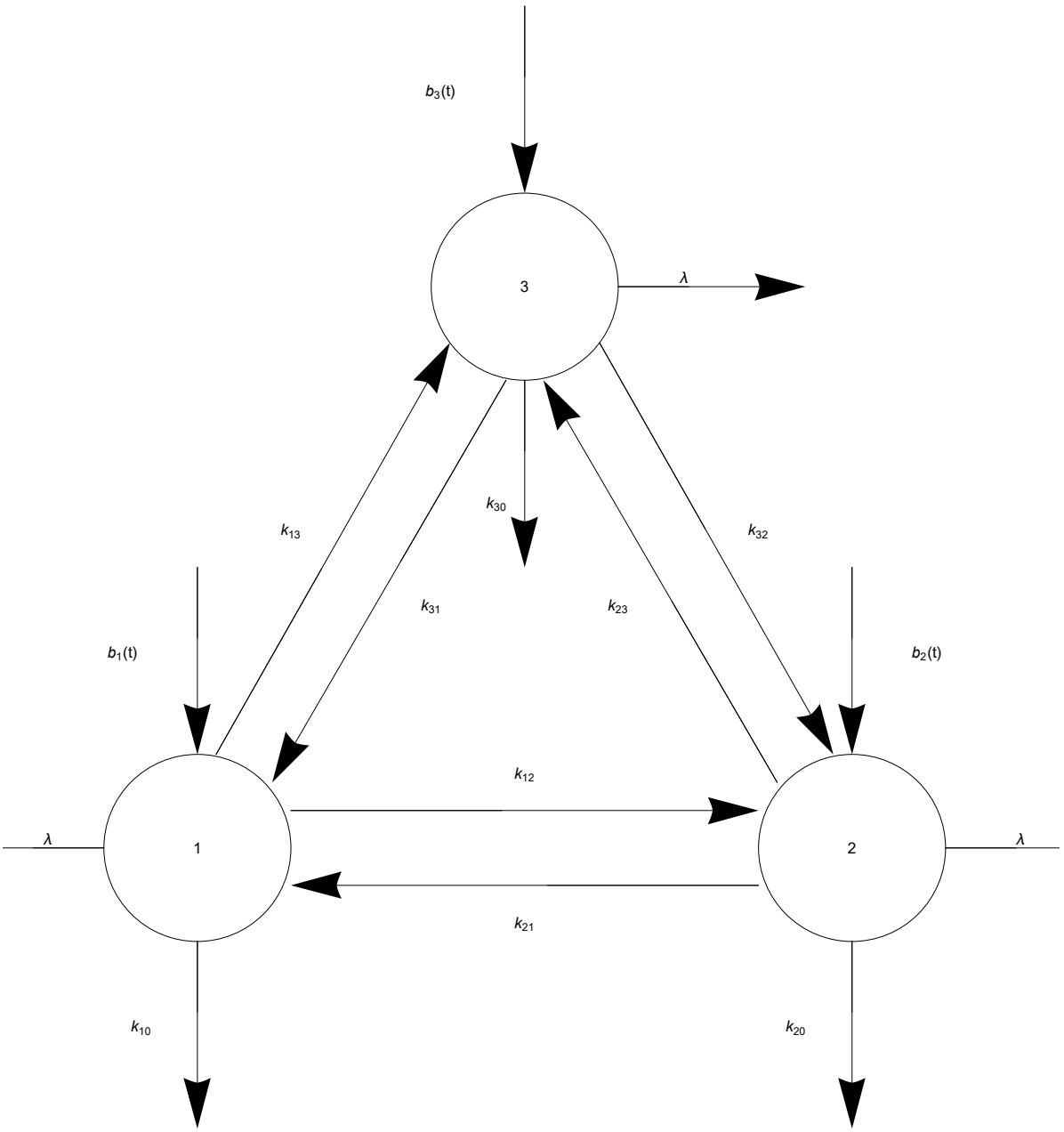
http://oed.usal.es/webMathematica/Biokmod/index.html



A simplified description of this method will shown in this presentation

Biokinetic modeling of the human body

Compartmental modelling has been used.



$$\dot{\mathbf{x}}(t) = \mathbf{A}\,\mathbf{x} + \mathbf{b}(t),\ t \geq 0$$

$$\mathbf{x}(0) = \mathbf{x}_0$$

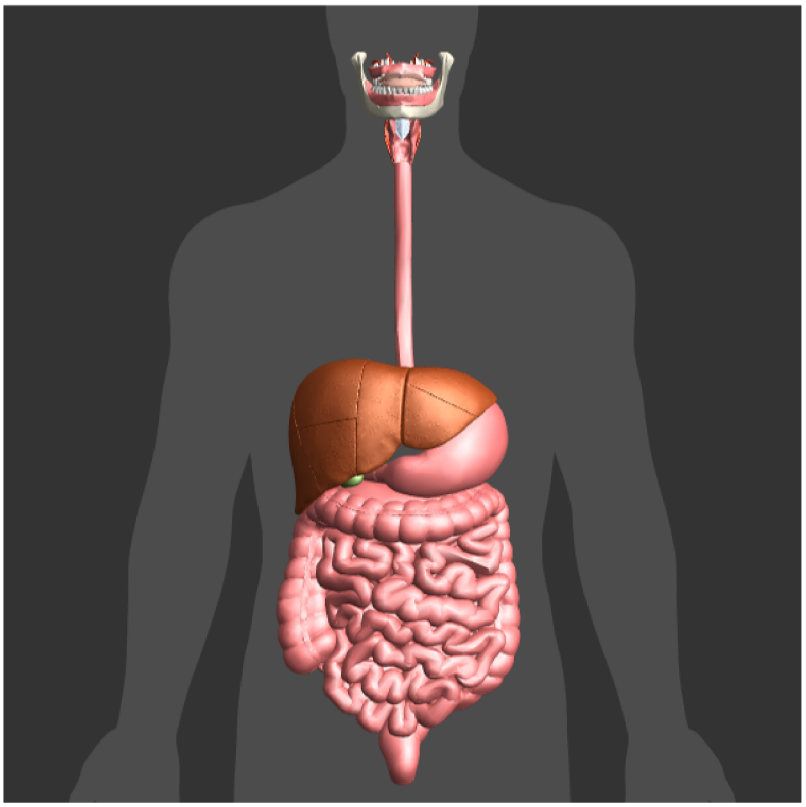
$x(t) = \{x_1(t),\ x_2(t),\ \ldots,\ x_n(t)\}^T$ is a column vector and $x_i(t)$ denote the amount or content of species in compartment i at time t.

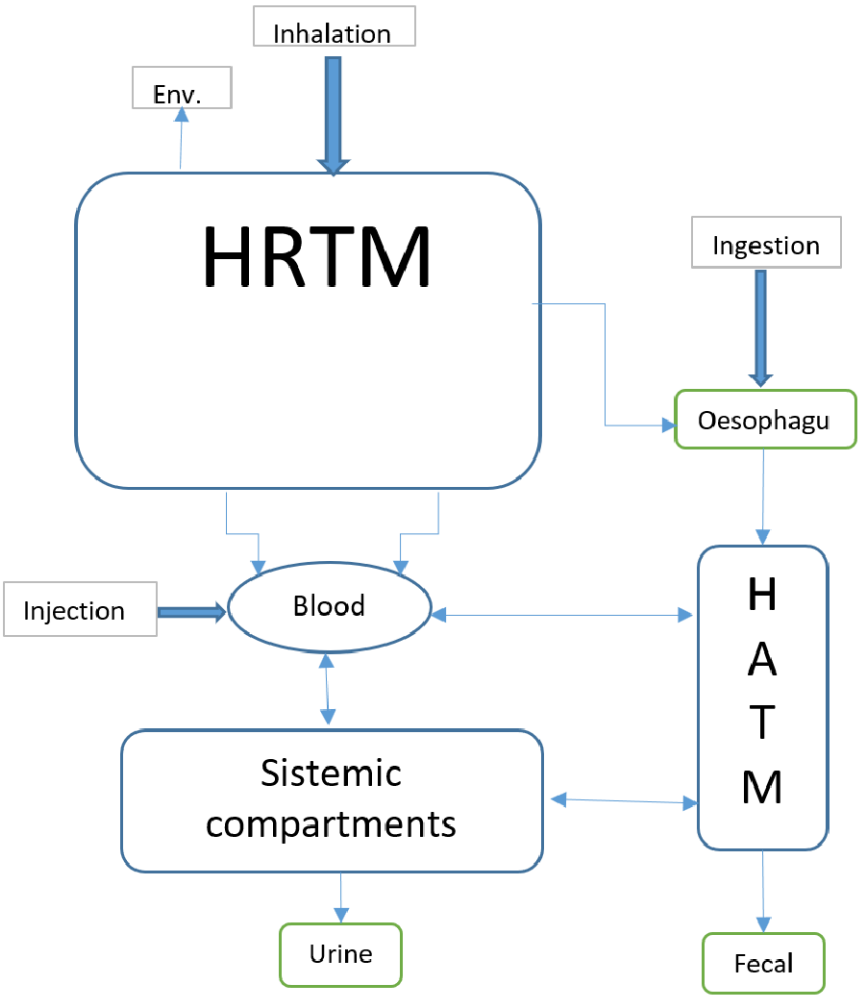
A is a $n \times n$ is usually known as the compartmental matrix or system matrix.

b$(t) = \{b_1(t),\ b_2(t),\ ..., b_n(t)\}^T$ is a column vector where $\{b_i(t)\}$ is the input rate into compartment *i* from outside system.

x$(0) = \{x_1(0),\ x_2(0),\ ...,\ x_n(0)\}^T$ are the initial conditions, so $x_i(0)$, represents the amount or content of species in compartment *i* at time $t = 0$.

The ICRP 130/ICRP 134 models are applied





The package

It has been included in a Mathematica package

In[•]:=
```
Needs["Biokmod`OIRModels`"]
```

```
SysModel, version 2.1   2024-06-28
```

```
OIRModels 1.2   2024-06-30
```

The response function

- If we assume a single intake of 1 Bq of U (as UO2 aerosols) the response function for urine excretion is:
- Approximation to daily urinary excretion:
- If we assume a constant intake of 1 BqU/d then the response function is:

Multiple random single intakes

Multiple single intakes simulation applied to different class of bioassay

A real case: Worker exposed long time to intake UO2

M.A. López , J. G. Sánchez-León , C. Hernández , M. Moraleda , J.M. Rodríguez-Díaz , I. Sierra, S. Sierra, D. García. Improving the reliability of internal dosimetry for uranium workers: application of the ICRP/OIR uranium model to long-term occupational intakes. Radiation Measurements. June 2024. https://doi.org/10.1016/j.radmeas.2024.107200

```
In[•]:= Needs["Biokmod`UO2intakes`"]
```

```
UO2intakes, version 1.0   2024-07-04
```

```
In[•]:= SetDirectory[FileNameJoin[{NotebookDirectory[], "Data"}]]
```

```
In[•]:= data = Import["DataEjemplo.xlsx", "XLSX"];
```

```
In[•]:= datos =
 Normal[GroupBy[{Round[#1], #2} & @@@ Extract[data, 1], First → Last, Total]] /.
  Rule → List; Shallow[datos]
```

```
Out[•]//Shallow=
{{5526, 0.09656}, {5618, 0.03343}, {5619, 0.10899}, {5620, 0.02372}, {5622, 0.02647},
  {5623, 0.09702}, {5624, 0.13714}, {5625, 0.31673}, {5626, 0.16865}, {5627, 0.03574}, ≪3417≫}
```

- Urine samples: {n (natural days since started the intakeo), m_n (BqU-234/d) , Statistical error (BqU-234/d)}

```
In[•]:= sampledata = {{10909, 0.002305, 0.00041}, {11265, 0.003345,  0.00129},
    {11924, 0.002035,  0.000360}, {12013, 0.002555, 0.0005},
    {12287, 0.001165, 0.00029}, {12363, 0.001035, 0.000302},
    {12646, 0.000885, 0.000309}, {12779, 0.000965,  0.000284}};
```

- Date of the worker start the intake

```
In[•]:= inicioincorporacion = {1985, 01, 15};
```

- Period to compute intake and dosesE(50):

```
In[•]:= {finio,  final} = {{2015, 01, 01}, {2016, 01, 01}};
```

- Uranium isotopic composition (U238, U235, U234)

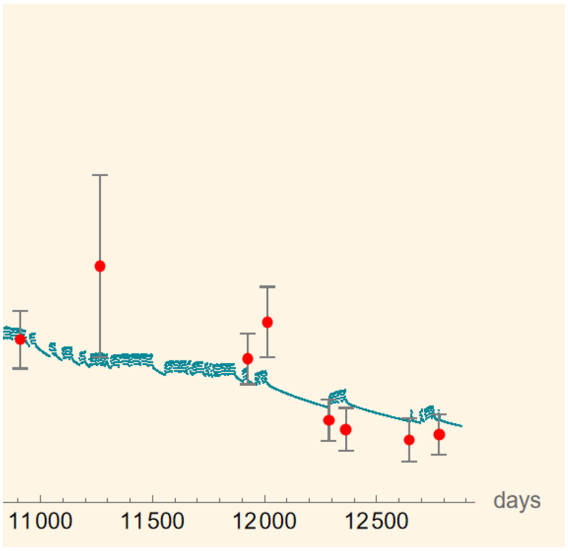
```
In[•]:= isowt = {95.765, 4.20, 0.035};
```

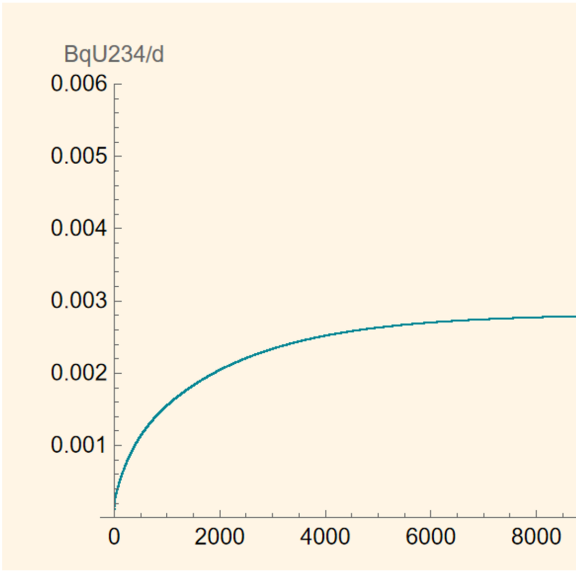
Computing the intake

In[•]:=
```
MultiinputsUO2Full[datos, sampledata, isowt, 180,
    {inicioincorporacion, finio, final}, "U234"] // Quiet // TableForm
```

Out[•]//TableForm=

Ji2 1.98037	rb_wd 2.14		
Intervalo T2 → $\begin{pmatrix} 2014 & 6 & 1 \\ 2020 & 1 & 12 \end{pmatrix}$	BqU/wd 0.117117	BqU/nd 0.040143	
Total BqU for T1 1394	Total mSv for T1 7.53	Total BqU for T2 82	Total mSv for T2 0.44
Actividad entre las fechas elegidas			
16 BqU	1.99 BqU−238	0.56 BqU−235	13.45 BqU−234
mSv entre fechas elegidas			
0.086 mSv U	0.01 mSv U−238	0.003 mSv U−235	0.074 mSv U−234





BIOKMOD

http://oed.usal.es/webMathematica/Biokmod/

Home | Compartmental Mod | OIR models | Bioassay Evaluation | ICRP 66/78 Models

Bioassay fit | Bioassay Multifit | UO2-orina (por fichero) | UO2-orina (por intervalos) | B

Input

Carga de fichero con las incorporaciones diarias del trabajador

Aquí se carga el fichero con los datos del trabajador. El fichero debe ser formato xlsx con dos columnas A y B con las incoporaciones diarias En las celdas de la columna A debe ir el día J (en númetos enteros contados) desde el día de incorporación del trabajador y en la columna B la actividad incorporada Ac(J, P) el día J en Bq U medida en el punto de muestreo P (admite que un mismo día tenga distintas incorporaciones).

Pulse aquí para descargar, y despues importar, el fichero utilizado como ejemplo

Introduzca el fichero de puntos: Elegir archivo DataEjemplo.xlsx

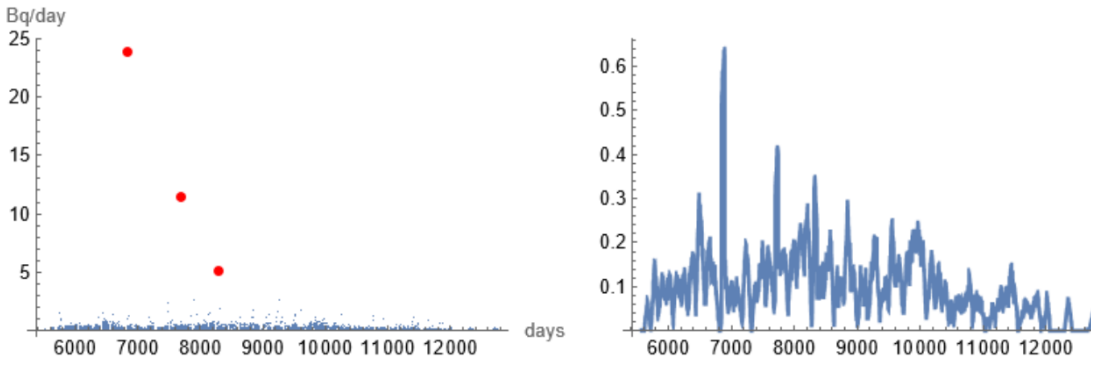
Pulse *Visualizar Puntos* para ver la representación gráfica del fichero importado.

El gráfico resultante muestra la media movil de las incoporaciones diarias, calculada a partir del fichero importado, con los datos de los últimos 50 días naturales.

Borrar Visualizar Puntos

Incorporaciones/dosis estimadas a partir de muestras de U en orina

Incorporaciones diarias y media móvil (50 valores) de las incorporaciones diarias



DATOS DE ENTRADA

Datos del trabajador: Caso ejemplo

Descripción de caso:

"Evaluación rutinaria"

Composición típica del uranio en el área en el que el trabajador está expuesto (% en peso) ´{U-238, U-235, U-234}, usese un valor típico del último periodo.

{95.765, 4.20, 0.035}

Marcar en el caso de que los datos de las muestras de orina correspondan a U-234 : ☑

Ingresar los valores de las muestras de orina {{t1, m1, u1}, {t2, m2, u2}, ...}, ti=tiempo en días (desde el que el trabajador empezó estar expuesto), mi=medida (Bq de U o U-234 en muestras de 24 h), ui=incertidumbre de la medida.

```
{{10909, 0.002305, 0.00041}, {11265, 0.003345, 0.00129}, {11924,0.002035,0.000360},
{12013, 0.002555, 0.0005}, {12287, 0.001165, 0.00029}, {12363, 0.001035, 0.000302},
{12646, 0.000885, 0.000309}, {12779, 0.000965,    0.000284}}
```

Límite del intervalo T1 (días antes o después (si escribe "-") a la primera muestra): 180

Fecha inicio exposición: {1985, 01, 15} Periodo cálculo dosis: fecha inicial {2015, 01, 01} Fecha final {2016, 01, 01}

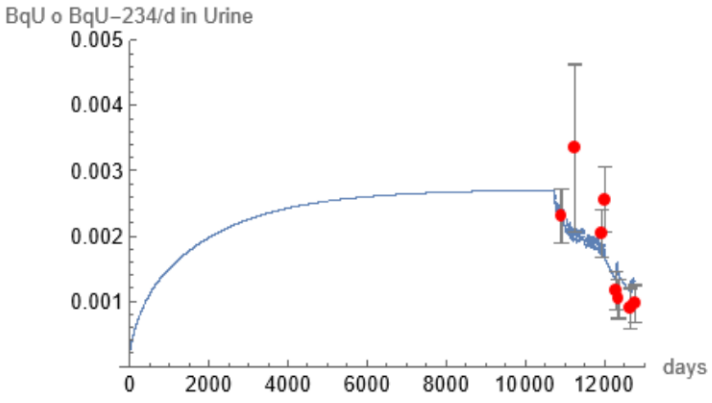
Representación gráfica: Límites inferior =OX en días: 10000

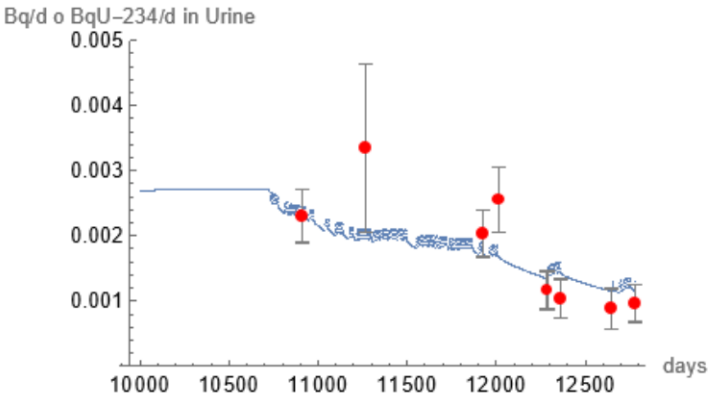
EVALUAR

Output

Nombre -> Caso ejemplo
Descripción -> "Evaluación rutinaria"
Fecha inicio exposición -> {1985, 01, 15}
Periodo para el que se estima la dosis: -> {{2015, 01, 01}, {2016, 01, 01}}
Muestras de orina de BqU o BqU-234 de 24 h -> {{10909, 0.002305, 0.00041}, {11265, 0.003345, 0.00129}, {11924, 0.002035, 0.000360}, {12013, 0.002555, 0.0005}, {12287, 0.001165, 0.00029}, {12363, 0.001035, 0.000302}, {12646, 0.000885, 0.000309}, {12779, 0.000965, 0.000284}}
Composición isótopica (% wt: {U238, U-235, U234}) -> {95.765, 4.20, 0.035}
Modelo biocinetíco: OIR ICRP 137/130
Coefs. dosis e(50). AMAD 5, M/S -> {0.0048* mSv/BqU238, 0.0051* mSv/BqU235, 0.0055*mSv/BqU234}

{Ji2, 1.98037}	{rb_wd, 2.14}	{BqU/wd, 0.117117}	{BqU/nd, 0.040143}
{Total BqU for T1, 1394}	{Total BqU for T2, 82}	{Total mSv for T1, 7.53}	{Total mSv for T2, 0.44}
Actividad entre las fechas elegidas			
16*BqU	1.99*BqU-238	0.56*BqU-235	13.45*BqU-234
mSv entre fechas elegidas			
0.086*mSv U	0.01*mSv U-238	0.003*mSv U-235	0.074*mSv U-234


BqU o BqU−234/d in Urine
0.005
0.004
0.003
0.002
0.001
0
2000
4000
6000
8000
10000
12000
days


Bq/d o BqU−234/d in Urine
0.005
0.004
0.003
0.002
0.001
10000
10500
11000
11500
12000
12500
days