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**DOSE ASSESSMENTS FROM WHOLE-BODY MEASUREMENTS –  
THE APPROACH AT NPP KOZLODUY**

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**Abstract** - Dose assessments from intakes of inhaled radionuclide present rather complex problems. It requires some information and comprehensive investigation and calculation. In addition ICRP has reviewed and changed some of the biokinetic models and adopted a new model for the human respiratory tract (ICRP Publications 56, 66, 67, 69). At NPP Kozloduy two programmes were applied for such type of dose assessments: CINDY 1.3 (USA), and AIDA (Activity and Intake Dose Assessments) (Local one), both based on ICRP Publication 30. The above circumstances were reflected in a new software named DOSEART, designed to meet the Bulgarian Radiation Safety Rules (ONRZ 2000) as well. The program DOSEART is verified against LUDEP 2.07 for some typical for NPP radio-nuclides. It is developed using Visual Basic 5.0 and is quite user-friendly and reliable.

## INTRODUCTION

The programme for monitoring the internal contamination at Nuclear Power Plant Kozloduy (KNPP) is based entirely on *in vivo* whole body measurements as the most convenient and rapid method for determining uptakes of radioactivity by inhalation. The counting system is Canberra type: Accuscan scanning bed position and the appropriate software for the estimation.

Whole-body counting determines the amount of radioactivity present in the body at the time of the measurements (an uptake), but it cannot determine the amount present at some previous time; that quantity must be inferred from the measured body content and from the application of metabolic models or retention curves that describe the behavior of the radionuclides in the body. Routine individual monitoring consists of regularly repeated measurements made on individual worker, while special monitoring is performed before and after particular task. The estimation of doses from radionuclides within the body (internal emitters) is less straightforward than with external radiation - internal dose cannot be measured directly. In the interpretation of the measurements the major source of uncertainty lies in the unknown intake times.

## INTERNAL DOSE ASSESSMENT

The KNPP's programme is based on routine and partly on special individual monitoring. Thousands of measurements are performed annually in the whole-body laboratory. If any activity is registered then the Health Physicist (HP) has to answer a couple of important questions:

- Is it external or internal contamination;
- What is the chemical form of the nuclides;
- When did it happened;
- What is the size of the inhaled aerosol (AMAD);

- Did all measured nuclides have the same size (AMAD);
- Do we have one or more intakes between the actual and previous measurements;
- How to estimate the actual if a previous intakes were registered;

On the other hand to estimate the dose from the measured activity we should know the biokinetic behavior of the particular radionuclide:

- the accumulation of activity in specific organs;
- the retention of radionuclides in those organs;
- the transport of radionuclides between organs;
- the removal by excretion and radioactive decay, of activity from the body;

To answer all these questions the HP should be quite experienced. The following two phases are inevitable when estimating the internal dose:

- Questioning phase;
- Investigation phase (individual metabolism);

The very important instrument, needed by the HP, is an actual user-friendly software. This paper will not deal with the mentioned above phases. We want to present our software that helps to calculate rapidly different input data and compare the results for those inputs.

#### THE SOFTWARE “DOSEART”

At NPP Kozloduy two programs were applied for such type of dose assessments: CINDY 1.3 [1] (USA), and AIDA (Activity and Intake Dose Assessments), local one, both based on ICRP Publication 30. Recently ICRP has reviewed and changed some of the biokinetic models and adopted a new model for the human respiratory tract (ICRP Publication 66 [2] ). The above circumstances were reflected in a new software named DOSEART, designed to meet the Bulgarian Radiation Safety Rules (ONRZ 2000) as well.

The program DOSEART is verified against LUDEP 2.07 [3] for some typical for NPP radionuclides. It is developed using Visual Basic 5.0 and is quite user-friendly and reliable. To fully describe the software will take more time and pages. So only some main features will be discussed here.

The values of the whole body intake retention fractions (IRF) from inhalation have been calculated in advance by preliminary developed application programmes - IRF generators. Whole body 's compartment model and matrix notation were applied. The IRF values are saved in form of a library, (data files), for different radionuclides, for AMADs 1 and 5 microns, types F, M, S, and time after intake (up to 700 days in step of 1 day). One IRF generator is based on the models as in ICRP Publication 30. The second one was created using the ICRP Publication 66 introducing the new lung model. Below the table gives values of IRF for different types and radionuclides, calculated with the second IRF generator and LUDEP 2.07.

Days	Type S, Co – 60 AMAD 1 micron		Type F, CS- 137 AMAD 1 micron		Type S, Co – 60 AMAD 5 micron		Type F, CS- 137 AMAD 5 micron	
	Inhalation IRF	LUDEP 2.07	Inhalation IRF	LUDEP	Inhalation IRF	LUDEP	Inhalation IRF	LUDEP 2.07
1	0.3447	0.3469	0.4881	0.4922	0.4881	0.4922	0.5974	0.5944
2	0.2202	0.2219	0.2508	0.2540	0.2508	0.2540	0.5062	0.5020
3	0.1617	0.1625	0.1417	0.1430	0.1417	0.1431	0.4663	0.4622
4	0.1373	0.1376	0.0974	0.0978	0.0974	0.0978	0.4466	0.4432
5	0.1272	0.1272	0.0798	0.0799	0.0798	0.0799	0.4352	0.4325
6	0.1225	0.1225	0.0726	0.0725	0.0726	0.0725	0.4279	0.4255
7	0.1201	0.1201	0.0693	0.0692	0.0693	0.0692	0.4223	0.4203
8	0.1184	0.1184	0.0675	0.0674	0.0675	0.0674	0.4178	0.4160
9	0.1171	0.1170	0.0663	0.0662	0.0663	0.0662	0.4138	0.4123
10	0.1158	0.1158	0.0653	0.0652	0.0653	0.0652	0.4101	0.4090
20	0.1061	0.1060	0.0584	0.0583	0.0584	0.0583	0.3828	0.3822
30	0.0985	0.0985	0.0536	0.0536	0.0536	0.0536	0.3593	0.3585
40	0.0926	0.0926	0.0500	0.0499	0.0500	0.0499	0.3366	0.3365
50	0.0877	0.0876	0.0471	0.0471	0.0471	0.0471	0.3160	0.3157
60	0.0836	0.0836	0.0447	0.0447	0.0447	0.0447	0.2967	0.2963
70	0.0801	0.0802	0.0427	0.0427	0.0427	0.0427	0.2796	0.2780
80	0.0774	0.0773	0.0412	0.0411	0.0412	0.0411	0.2605	0.2608
90	0.0746	0.0747	0.0396	0.0397	0.0396	0.0397	0.2445	0.2447
100	0.0726	0.0726	0.0385	0.0385	0.0385	0.0385	0.2296	0.2296

In case of a multiple or a continuous intake, the total intake  $I_{TOTAL}$  could be approximated by an effective single intake and its relation to the whole body activity  $A(T)$ , is given by the following expression:

$$I_{TOTAL} = \frac{A(T)}{IRF_{EFFECTIVE}}$$

In case of continuous intake for a period  $T$ , the expression for the effective IRF is as follows:

$$IRF_{EFFECTIVE} = \frac{A(T)}{I_{TOTAL}} = \frac{\int_0^T I(t) \cdot IRF(T - t) dt}{\int_0^T I(t) dt}$$

In case of multiple  $N$  intakes, the expression is:

$$IRF_{EFFECTIVE} = \frac{A(T)}{I_{TOTAL}} = \frac{\sum_{k=1}^n I_k \cdot IRF_k}{\sum_{k=1}^n I_k}$$

Using the assumption for a constant intake rate, the above expression is simplified to:

$$IRF_{EFFECTIVE} = \frac{1}{T} \int_0^T IRF(t) dt$$

$$IRF_{EFFECTIVE} = \frac{\sum_{k=1}^n IRF_k}{n}$$

To calculate the dose from the estimated intake, the appropriate dose coefficients from BSS 115 [4] are used. They are tabulated in the programme for the selected types, AMAD and radionuclides. The advantages of the software “DOSEART”, when comparing with older versions as Cindy, should be quite easy understandable by experienced in the topic Health Physicist. Some of them are listed below:

- the time for input data and calculations is much shorter;
- easy to see and change all input data;
- previous intakes are taken into account when estimating the actual one;
- possibility to estimate multiple intakes;
- calculation modes for special and routine monitoring;
- calculated intakes and doses are given at the same time;
- when input of many radionuclides, all intakes and doses are partially presented;
- percentages of ALI for each of the radionuclides are presented;
- the programme automatically changes the values when dimensions are changed;
- doses for continuous intake are evaluated;
- implementation of the new lung model;

No report output is considered disadvantage of the software. However DOSEART is used in the investigation phase and for theoretical studies. When necessary the values are put into the legal certificate form.

Four typical screens of the programme are shown at the end. They illustrate different modes and calculation for selected radionuclides.

## References

- [1] CINDY , Batelle Pacific Northwest Laboratories, USA, DOE Order 5480.11 , 1992
- [2] ICRP Publication 66, Human Tract Model for Radiological Protection, Ann. ICRP 24, 4. Pergamon Press, Oxford UK, 1994
- [3] Jarvis N.S., Birchall A., James A.A., Bayley M. R. and Dorian M.D , LUDEP 2.0 -Personal computer programme for calculating internal doses using the ICRP Publication 66 respiratory tract model, Chilton, NRPB -SR 287 , 1996
- [4] International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, Safety Series No.115, IAEA, 1996

**DOSE ART** New Lung Model (ICRP publication 66)

**Radionuclide DATA**

Area ☐ Activity ☒ Previous Intake

Nuclide	Class	Amad	Bq	Bq
<input type="checkbox"/> Co-58				
<input checked="" type="checkbox"/> Co-60	S	5	1000	2000
<input type="checkbox"/> Cs-134				
<input checked="" type="checkbox"/> Cs-137	F	5	1000	
<input checked="" type="checkbox"/> Mn-54	M	5	1000	
<input checked="" type="checkbox"/> Ag-110m	S	5	1000	
<input type="checkbox"/> Zr-95	F			
<input type="checkbox"/> Nb-95	M			
<input type="checkbox"/> Cr-51	S			
<input type="checkbox"/> Fe-59				
<input type="checkbox"/> Zn-65				
<input type="checkbox"/> Ru-103				
<input type="checkbox"/> Ru-106				
<input type="checkbox"/> I-131				
<input type="checkbox"/> Ce-141				
<input type="checkbox"/> Ce-144				

**Additional DATA**

Measurement Time: [seconds] 800

Personal Data

Age [years]:

Weight [kg]: 70

Monitoring

☒ Routine ☐ Special

Routine Monitoring

Measurement: [dd.mm.yy]

current: 10.04.02

previous: 18.01.02

before previous: 19.10.01

Intake

☒ Acute ☐ Multiple ☐ Continuous

24.11.01 02.03.02

**Final RESULTS**

	ACTIVITY	INTAKE	DOSE
Co-58			
Co-60	0.027	18484	0.31
Cs-134			
Cs-137	0.027	2945	0.02
Mn-54	0.027	16681	0.02
Ag-110m	0.027	18871	0.14
Zr-95			
Nb-95			
Cr-51			
Fe-59			
Zn-65			
Ru-103			
Ru-106			
I-131			
Ce-141			
Ce-144			
<b>TOTAL:</b>	56981		0.49

Calculate New Data End

Company: Name: Department: Code: Sector: Comments: Print

**DOSE ART** New Lung Model (ICRP publication 66)

**Radionuclide DATA**

Area ☐ Activity ☒ Previous Intake

Nuclide	Class	Amad	Bq	Bq
<input type="checkbox"/> Co-58				
<input checked="" type="checkbox"/> Co-60	S	5	1000	2000
<input type="checkbox"/> Cs-134				
<input checked="" type="checkbox"/> Cs-137	F	5	1000	
<input checked="" type="checkbox"/> Mn-54	M	5	1000	
<input checked="" type="checkbox"/> Ag-110m	S	5	1000	
<input type="checkbox"/> Zr-95				
<input type="checkbox"/> Nb-95				
<input type="checkbox"/> Cr-51				
<input type="checkbox"/> Fe-59				
<input type="checkbox"/> Zn-65				
<input type="checkbox"/> Ru-103				
<input type="checkbox"/> Ru-106				
<input type="checkbox"/> I-131				
<input type="checkbox"/> Ce-141				
<input type="checkbox"/> Ce-144				

**Additional DATA**

Measurement Time: [seconds] 800

Personal Data

Age [years]:

Weight [kg]: 70

Monitoring

☒ Routine ☐ Special

Routine Monitoring

Measurement: [dd.mm.yy]

current: 10.04.02

previous: 18.01.02

before previous: 19.10.01

Intake

☒ Acute ☐ Multiple ☐ Continuous

24.11.01 02.03.02

**Final RESULTS**

	ACTIVITY	INTAKE	DOSE
Co-58		microCi	
Co-60	0.027	18484 Bq	0.31
Cs-134		% ALI	
Cs-137	0.027	0.10	0.02
Mn-54	0.027	0.10	0.02
Ag-110m	0.027	0.69	0.14
Zr-95			
Nb-95			
Cr-51			
Fe-59			
Zn-65			
Ru-103			
Ru-106			
I-131			
Ce-141			
Ce-144			
<b>TOTAL:</b>	2.46		0.49

Calculate New Data End

Company: Name: Department: Code: Sector: Comments: Print

**DOSE ART** New Lung Model (ICRP publication 66)

**Radionuclide DATA**

☐ Area ☒ Activity Previous Intake

Nuclide	Class	Amad	Bq	Bq
<input type="checkbox"/> Co-58				
<input checked="" type="checkbox"/> Co-60	S	5	1000	2000
<input type="checkbox"/> Cs-134				
<input checked="" type="checkbox"/> Cs-137	F	5	1000	
<input checked="" type="checkbox"/> Mn-54	M	5	1000	
<input checked="" type="checkbox"/> Ag-110m	S	5	1000	
<input type="checkbox"/> Zr-95				
<input type="checkbox"/> Nb-95				
<input type="checkbox"/> Cr-51				
<input type="checkbox"/> Fe-59				
<input type="checkbox"/> Zn-65				
<input type="checkbox"/> Ru-103				
<input type="checkbox"/> Ru-106				
<input type="checkbox"/> I-131				
<input type="checkbox"/> Ce-141				
<input type="checkbox"/> Ce-144				

**Additional DATA**

Measurement Time: [seconds] 800

**Personal Data**

Age [years]:

Weight [kg]: 70

**Monitoring**

☒ Routine ☐ Special

**Routine Monitoring**

Measurement: [dd.mm.yy]

current: 10.04.02

previous: 18.01.02

before previous: 19.10.01

**Intake**

☐ Acute ☐ Multiple ☒ Continuous

**Final RESULTS**

	ACTIVITY	INTAKE	DOSE
	microCi	Bq	mSv
Co-58			
Co-60	0.027	13150	0.22
Cs-134			
Cs-137	0.027	2839	0.02
Mn-54	0.027	12300	0.01
Ag-110m	0.027	13694	0.10
Zr-95			
Nb-95			
Cr-51			
Fe-59			
Zn-65			
Ru-103			
Ru-106			
I-131			
Ce-141			
Ce-144			
<b>TOTAL:</b>	<b>41983</b>	<b>0.36</b>	

Company:  Name:

Department:  Code:

Sector:  Comments:

**DOSE ART** New Lung Model (ICRP publication 66)

**Radionuclide DATA**

☐ Area ☒ Activity Previous Intake

Nuclide	Class	Amad	Bq	Bq
<input type="checkbox"/> Co-58				
<input checked="" type="checkbox"/> Co-60	S	1	1000	2000
<input type="checkbox"/> Cs-134		1		
<input checked="" type="checkbox"/> Cs-137	F	5	1000	
<input checked="" type="checkbox"/> Mn-54	M	5	1000	
<input checked="" type="checkbox"/> Ag-110m	S	5	1000	
<input type="checkbox"/> Zr-95				
<input type="checkbox"/> Nb-95				
<input type="checkbox"/> Cr-51				
<input type="checkbox"/> Fe-59				
<input type="checkbox"/> Zn-65				
<input type="checkbox"/> Ru-103				
<input type="checkbox"/> Ru-106				
<input type="checkbox"/> I-131				
<input type="checkbox"/> Ce-141				
<input type="checkbox"/> Ce-144				

**Additional DATA**

Measurement Time: [seconds] 800

**Personal Data**

Age [years]:

Weight [kg]: 70

**Monitoring**

☒ Routine ☐ Special

**Routine Monitoring**

Measurement: [dd.mm.yy]

current: 10.04.02

previous: 18.01.02

before previous: 19.10.01

**Intake**

☐ Acute ☐ Multiple ☒ Continuous

**Final RESULTS**

	ACTIVITY	INTAKE	DOSE
	microCi	Bq	mSv
Co-58			
Co-60	0.027	8145	0.24
Cs-134			
Cs-137	0.027	2839	0.02
Mn-54	0.027	12300	0.01
Ag-110m	0.027	13694	0.10
Zr-95			
Nb-95			
Cr-51			
Fe-59			
Zn-65			
Ru-103			
Ru-106			
I-131			
Ce-141			
Ce-144			
<b>TOTAL:</b>	<b>36978</b>	<b>0.37</b>	

Company:  Name:

Department:  Code:

Sector:  Comments: