
OEDIPE: a New Numerical Tool for the Personalized Internal Dose Assessment

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Abstract:

Within the framework of radiation protection or internal radiotherapy, one of the major stakes is to determine in a most realistic possible way the dose received by every patient. In this purpose, a tool called OEDIPE, French acronym for “tool for personalized internal dose assessment”, was developed at IRSN associating numerical voxelized phantoms, created with anatomical images, and Monte Carlo calculation. After a presentation of the principal functionalities two examples illustrating the potential detailed demonstrating the interest and the potential of the software OEDIPE in case of internal contamination and in internal radiotherapy leads.

1 INTRODUCTION

The OEDIPE software was developed to meet the needs of the internal dosimetry in two particular fields of application: the radioprotection and the nuclear medicine. Indeed, the incorporation of radionuclides in the human body can arise in a accidental or voluntary way. On one side, the use of radioactive sources in the industry, the medicine or the research exposes the population and particularly the workers to possible internal contaminations, by inhalation, ingestion or wound. Of other one, the internal administration of radionuclides is also used in the medical domain, in nuclear medicine. The nuclear medicine, being originally a technique of medical imaging with diagnosis aim, developed towards therapeutic applications notably for the treatment of cancers.

In the case of an accidental internal exposure one of the first concerns is to estimate quickly and in a reliable way the scale of the contamination, its nature and its anatomical distribution, to drive the sanitary care. For that purpose, the activity of contaminants must be determined, notably by *in vivo* monitoring, to determine then the dose received in various tissues.

The *in vivo* monitoring systems are classically calibrated by means of physical phantoms, which are nevertheless only the very approximate reflection of the anatomy of the contaminated person. So, the OEDIPE code allows to free itself from this problem as far as spectra supplied by this tool allow to realize a specific calibration of the installation on the basis of the appropriate morphology for the person. The result of the *in vivo* measurement allows then to characterize in a more realistic way the contamination of the studied body.

In the case of the nuclear medicine and in particular the vectorized radiotherapy, the dosimetric studies realized *a priori* can help to optimize the standard treatment by personalizing it while minimizing the associated risks. Realized *a posteriori*, they can improve the knowledge of the therapeutic relation dose-effect of the treatment.

In this frame, the results of OEDIPE presented in the form of values of internal doses received at the level of organs or directly on the image MRI (or CT scan) from the patient by superimposing of isodoses curves can bring a help to the nuclear physician. In both cases, OEDIPE is not a tool of diagnostic but a tool of help to the medical decision.

2 PRÉSENTATION OF OEDIPE

The purpose of the software OEDIPE is to recreate in a faithful and personalized way all the parameters relative to an *in vivo* measurement or to estimate the dose delivered in the organs of a person following an internal exhibition exposure (accidental or deliberated as in nuclear medicine). The figure 1 presents a general description of the features of OEDIPE. It is conceived on the basis of a friendly graphic interface, the originality lies in its possibility of reconstructing personalized numeric phantoms created from medical images (CT scan or MRI), of generating in a automatic way the input file for the calculation code of transport of particles MCNPX (1) and of showing in a simple way the results obtained by the calculation. The global features of OEDIPE are defined according to the following stages:

- Import of the data supplied by the images scanner or MRI of the person and construction of a numerical phantom with segmentation of organs and their densities,
- Location of the sources of contamination (type of sources, type of radioelements, activity),
- Definition and location of the detectors (in case of *in vivo* measurement),
- Automatic Creation of a MCNPX input file
- Analysis of the MCNPX output file supplying two types of possible data:
 - Doses in organs or distributions in the tissular isodose scale.
 - Spectra allowing the comparison between simulation and measurement.

The crucial point of the realization of the simulation is the implementation of input data of the system. They are three orders: i) the tomographic images of a phantom or a person, ii) the description of the source, namely the type of source (point or volume), its distribution in organs and tissues, their energy and their probability of emission, as well as activity and measurement time, allowing directly to compare calculation and measurement and finally, iii) for the activity measurement, the geometry of the detector and its location with regard to the numerical phantom.

All these data are taken into account during the creation of the MCNPX input file.

The segmentation of the images is based on the various levels of grey contained in the image; the various organs or tissues) so bounded are then associated with the tissular densities.

A detailed description of this interface is available in the references (2-5).

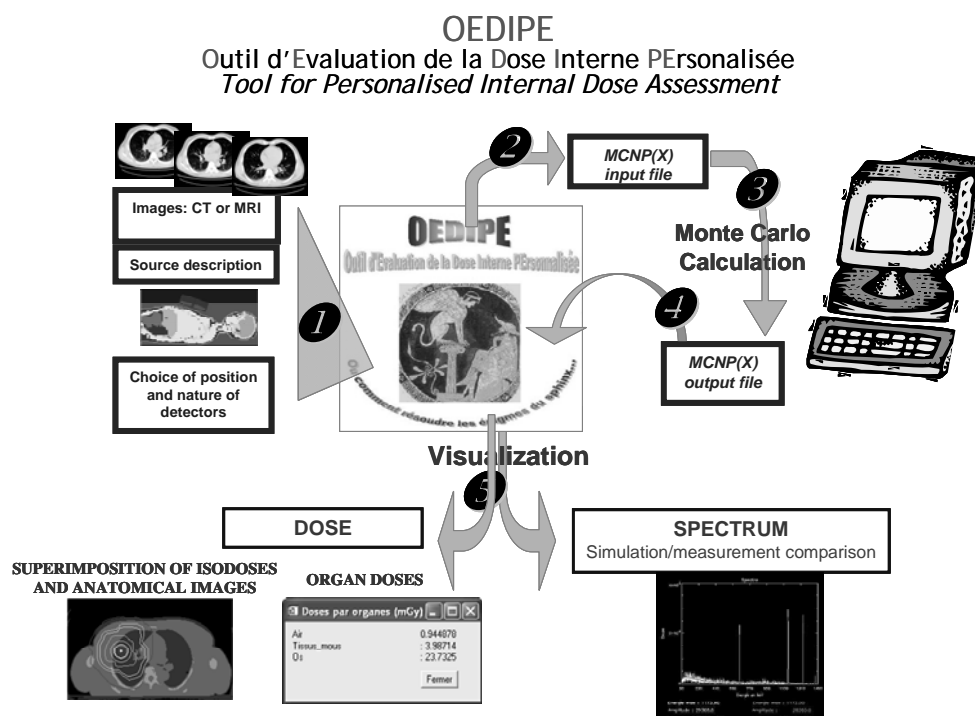


Figure 1: Overview diagram of the software OEDIPE: ❶ Input data necessary for the creation of the MCNPX input file (source(s), detector (s), geometry of detection), ❷ Automatic creation of the MCNPX input file, ❸ MCNPX Calculation, ❹ Reading and extraction of the data of the MCNPX output file, ❺ Visualization of the data (dose or spectra of energy).

3 SOME EXAMPLES OF SCIENTIFIC WORKS

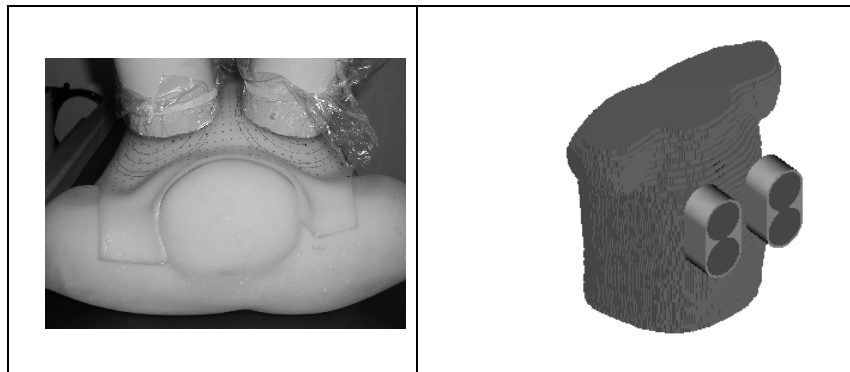
3.1 Application of OEDIPE for internal contamination of workers

The interest of the numeric phantoms and the Monte Carlo simulation through OEDIPE was demonstrated by the study of concrete and realistic cases of contamination, not accessible by the classic method of *in vivo* measurement, especially in the case of complex geometries such as lungs or of wound.

A study of validation was notably led in association with AREVA/COGEMA (Marcoule, France) which possesses a system of counting consisted of 4 germanium detectors representative of the French systems used in routine (6-7).

Having modeled the installation and the measurement geometry by using OEDIPE (figure 2), the validation was carried out in two stages with various configurations: i) first of all, with punctual sources (different nuclides, different source-detector geometries), then ii) with a Livermore phantom equipped with lungs loaded with a known ²⁴¹Am activity.

The results showed differences of less than 10 % between simulations and measurements confirming the potential of OEDIPE for the simulation of a real counting system (figure 3).



2a2b

Figure 2: photo of the installation of lung measurement of the AREVA Laboratory with the Livermore Phantom (a) and its simulation (b).

The digital calibration brings naturally important improvements from the point of view of the morphological correspondence between phantom and person, but also a better consideration of the realistic distribution of contamination, whether it is at the level of lungs or contaminated wounds on which there is at present no phantom of calibration; a numerical approach thus seems almost unavoidable to make a satisfactory estimation of the contamination activity. The method was successfully applied in several real cases of incident of contamination by wound. It has allowed an improvement of the determination of the source localization and the estimation of the residual activity and so led to refine the dosimetric calculation (8-10).

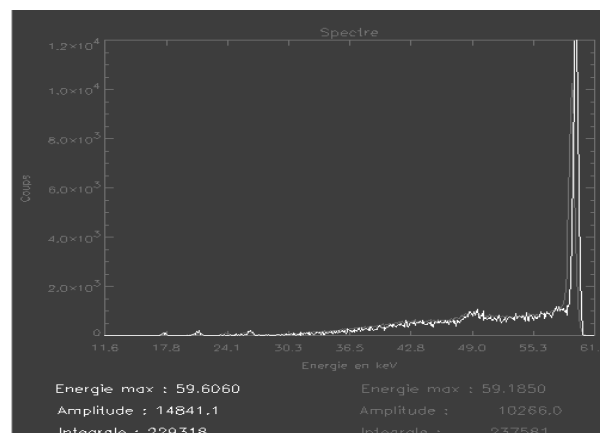


Figure 3: comparison of the simulated spectrum (white) and experimental (grey)

3.2 Application of OEDIPE in Nuclear Medicine

The works of the PhD work realized in 2006 by Sophie Chiavassa (3), allowed showing the interest of OEDIPE by comparing experimental and simulated results in the framework of the nuclear medicine. At this end, a device consisted of a radioactive sphere simulating a labeled tumor placed in the liver of the phantom Liqui-Phil™ ® was realized (figure 4).

Three dosimetric thermoluminescent threads were placed on each side of the tumor. The liver and the sphere were filled with activities of 78.5 and 256 MBq respectively. Then, the phantom was created with CT images to supply the input parameter of the geometry necessary for OEDIPE. The corresponding values of dose (Gy) were then determined automatically with OEDIPE from the deposits of energy, the mass of every voxel and the cumulated activities in source regions. The average absorbed doses calculated and measured in every thread were close and presented ratios of 1.1, 0.99 and 0.93. So, the comparison between the experimental results and the ones obtained with OEDIPE was satisfactory and validated the use of OEDIPE (3) (11).

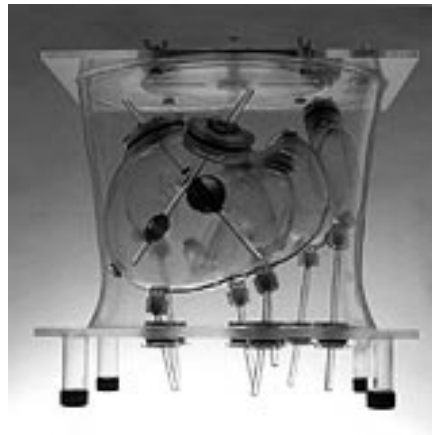


Figure 4 : Physical phantom Liqui-Phil®

Finally, the OEDIPE software was exploited in the domains of radioprotection and vectorised radiotherapy to estimate the dosimetric impact of a bad labeling of a diagnosis agent of bone scan and is currently tested for the implementation of a protocol of personalized dosimetry for the treatment of hepatocellular carcinomas by intra-arterial injection of ^{131}I -labeled lipiodol (LipiodolTM) (12-13).

The first dosimetric estimation was carried out on a patient having developed pneumopathy. He presented a very strong dose in the tumor (476 Gy) and relatively weak doses in the liver and the lungs. Doses calculated with a standard mathematical phantom and the software MIRDOSE.3 (14) present 6 % variations for the tumor, 65 % for the liver and 45 % for lungs (table 1).

However, the dose in organs is an insufficient information because it can bring only an average dose. It does not allow to detect zones of over or sub dosage. On the contrary, the dosimetry at the scale of the voxel allows having a spatial distribution of the dose inside organs (figure 5) and brings more information. On this patient, we can see that there is no overdose in lungs.

organs / tissus	OEDIPE	r. e.	MIRDOSE.3	Ratio OEDIPE / Mirdose.3
	Dose (Gy)	(%)	Dose (Gy)	(%)
Tumor	476.5	0.8	505.2	5.9
Healthy Liver	18.97	0.5	11,5	65,4
Right Lung	2.89	2.41		
Left Lung	1.49	3.96		
Lungs	2.283	2.94	1.57	45.4
Bone	0.56	1.87		
Soft tissue	0.62	0.71		

Table 1: Organ Doses (NPS = 100 000 CPU = 5.26 min)

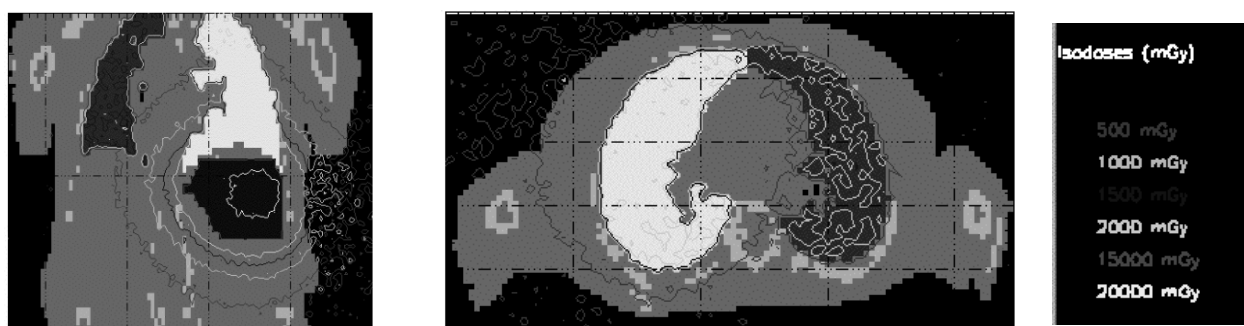


Figure 5: Spatial distribution of Dose: NPS =100 000 000 CPU = 4.67 days

4 CURRENT AND PERSPECTIVE IN RESEARCHES ON OEDIPE

The demonstration of the interest and the operation in routine of the software OEDIPE in case of internal contamination and in internal radiotherapy leads to new areas of research to optimize the application. As a matter of fact, dosimetric calculation being dependent on the determination of the accumulated activity, the idea is to exploit and to spread the capacities of OEDIPE to the calculation of the spatial distribution of the accumulated activity.

In case of internal contamination, the determination of the quantity of radionuclides retained at a given time in the body is generally determined by *in vivo* monitoring measurement and radiochemical analysis of excreta. The use of biokinetic models proposed by the ICRP (15) allows then, on one hand, to go back to the quantity of incorporated radionuclides, and on the other hand, to determine the future of this incorporated radioactive material by knowing its spatial and temporal distributions in the body. The OEDIPE software already possesses a module of simulation of the *in vivo* measurement. The implementation of the biokinetic models in the software OEDIPE has been the object of the PhD work of Stéphanie Lamart (16) and the application on real cases is in process.

In external radiotherapy, the calculation of the dose delivered by the ionization radiations is "mastered". Indeed, the source of radiations is outside and thus independent from the patient. The characteristics of the beam can be measured and are known perfectly.

The dosimetry of treatments in external radiotherapy is practiced for several decades, what allowed establishing a dose-effect relation for tumors and various healthy tissues. Today, from these data, predictive dosimetry is carried out for every treated patient what allows to adapt and to optimize treatments in a personalized way. It is also the purpose for in vectorized radiotherapy, but during internal irradiation, the biological and pharmacokinetic parameters vary from a patient to the other one. The parameters of the source of radiations are thus dependent on the patient and must be estimated for each of them. The calculation of the activity accumulated by quantitative imaging depends on methods of acquisition and on the data processing. At present, no protocol of quantification makes reference.

Furthermore, the spatial resolution of the calculation is limited by the systems of detection used. Numerous researches are made in this domain. As for the dosimetric calculation, the solution of the problem raised by the quantification could be the use of a Monte Carlo approach.

Therefore, OEDIPE should, in a near future, become a complete tool capable of realizing every stage of a personalized dosimetric study, and this, as well in case of internal contamination as in vectorized radiotherapy. Besides, as in the framework of the *in vivo* measurement, the consideration of the biokinetic data in the modeling of the source will be integrated into the calculation of dose, notably for the radiopharmaceutical compounds.

The calculations will be realized from the phantoms of man, woman and reference children adopted by the ICRP and should be the object of an intercomparison with the working groups of the ICRP in the next future.

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