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# COMPARISON BETWEEN THE RESULTS OF ABSORBED DOSES IN ORGANS BY COMPUTER PROGRAMS MCNP 4C, CALDOSE X AND PCXMC IN PATIENTS SUBMITTED IN DIAGNOSTIC RADIOLOGY EXAMS.

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## ABSTRACT

The x-rays to diagnostics are composed of several radiographic parameters that may be since from the biotype of the patient until the composition of radiographic techniques. According to the composition of the parameters adopted by operators of the equipment, the absorbed doses in organs ($D_{organs}$) of patients may vary. In this paper, has been used the programs MCNP 4C, CALDose X and PCXMC to determine the Dorgans based on same radiographic parameters of spectrum, generated by the incidence of X-ray source associated with the skin-focus distance and antero-posterior incidence (AP). The computational phantoms used were Xman1 Mird (ManRay 3.0) to MCNP 4C, MASH to the CALDose X and Rando to PCXMC. The organs and $D_{organs}$ studied were lungs, stomach and thyroid in the three software. The results that will be obtained possess the purpose of showing the agility and easiness, of programs of low cost or liberate in order to they obtain satisfactory results compared to MCNP 4C.

## 1. INTRODUCTION

With the increase of X-ray use in medical applications for diagnostics purposes, has became necessary the know the given doses in the patients for comparison to reference levels in radiodiagnostics or radiation risk. Experimental and computational process are widely used with this purpose, for this purpose the software has turned an important tool to feed the impossibility for take “in-vivo” measures in patients submitted to the exams. The validation of different software for specific conditions of exposure of patients is determinant for the reliability of its use [1].

Thus verification of these software come to meet the need to know better their functions, skills, processing time, handling convenience, kind of results and which way is viable comparing to developing of research or learning. Another relevant aspect to determine which software to choose, is how they are sold, in some instances they are not economically viable or have restrictions to their sale.

The software that calculate the absorbed doses in organs need to be fast in processing, especially if it is used to learning activities, but with satisfactory results, closest possible of real doses. The time of processing depends of high-performance computers or the accuracy of results and the relation between them.

In this paper, we performed a comparison of three software that calculates absorbed doses or indexes for subsequent conversion to absorbed doses, in order to be analyzed before its developing, which were delimited to calculate in the organs: Lungs, Stomach and Thyroid. This delimitation is based on the same parameters as the composition of radiographic techniques. The results that will be obtained possess the purpose of showing the agility and easiness, of low costs software or freeware that obtain satisfactory results compared to MCNP4C.

## 2. MATERIALS AND METHODS

To this paper, has been used three software that are based in probability and statistics of interaction between radiation and matter, grounded in the Principles of Monte Carlo. The software are PCXMC version 1.5 [2], CalDose X version 4.1 [3] and MCNP4C [4].

The radiographic technique is determined in equal parameters and are reasoned in a voltage of 110 kV, charge applied on X-rays tube of 20 mA.s, total filtration of tube in 2,5 mm AL, tungsten anode angle of 17º, focus skin distance (FSD) of 155 cm and range between focus and detector (film) of 180 cm, irradiation field size in the detector center of 35 x 40 cm², positioning of top of the irradiation field from T4 thoracic vertebra, postero-anterior projection (PA) to the chest and the same spectra energy relative to intensity x energy.

### 2.1. Simulations with the PCXMC

Has been inserted in the PCXMC the spectra values in the input files to generate calculations following the applied charge to the X-ray tube and all the others parameters. On Fig. 1 is presented the spectral used in these simulations.

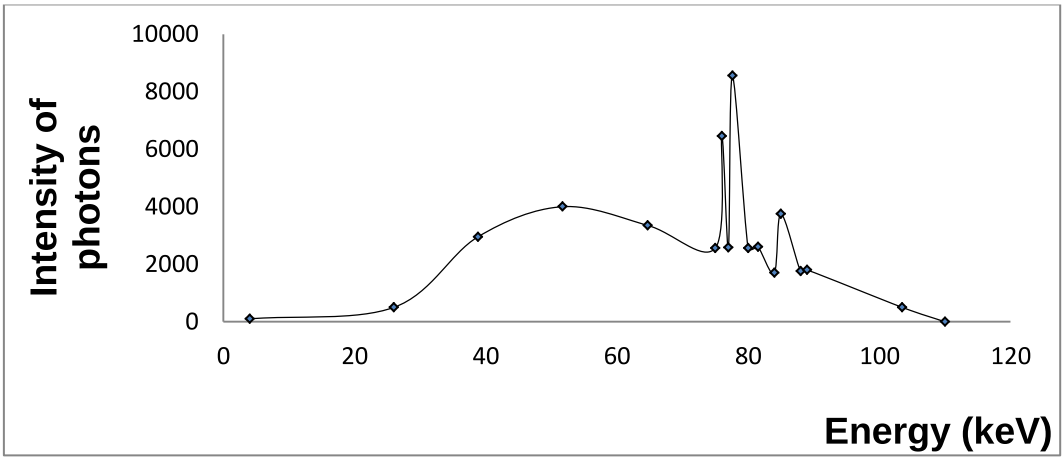



**Figure 1. Energy spectral of intensity x energy (keV).**

For the generate doses and statistics errors has been generated 2 x $10^7$ energy photons for each pack of 10 keV reaching 150 keV with processing time of 18 minutes and 30 seconds in a computer 1.8 Ghz processor and 2 GB of Ram. The parameter of applied charge to the X-ray tube was 20 mA.s for generation and composition of absorbed doses, since it has not the air kerma values. This software uses a mathematical hermaphrodite phantom MIRD5 (2) (3) based on Cristy and Eckerman Phantom (5) (6) with adult biotype with height of 174 cm, 70 kg, 30 year old. On Fig. 2 you may identify one of the screens of this software.

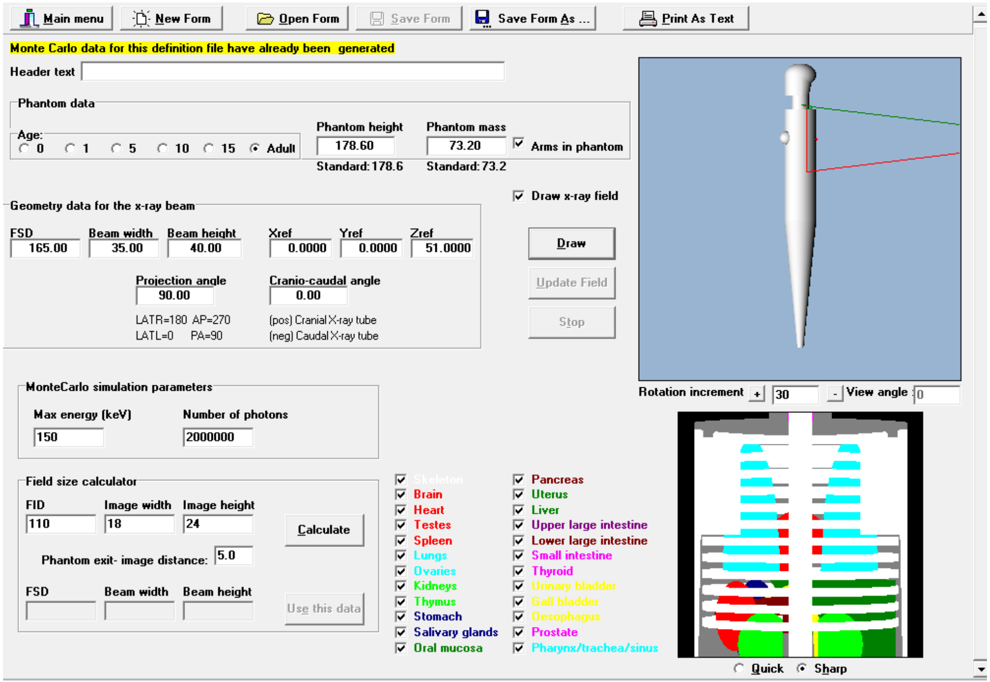



**Figure 2. Screen of PCXMC to insert radiographic parameters.**

This screen allows the user to insert the biotype, focus skin distance, size of irradiation field and its position on phantom, incidence angle of technique, number of photons and the selection of organs of interest for this radiographic technique.

## 2.2. Simulations with the CalDose X

In this simulation has been used the standard yield curve of the software as presented on Fig. 3 that depends of applied tension of 110 V, applied charge in X-ray tube and the focus skin distance. This software has not processing time neither photons numbers for generate the interactions between radiation and matter.

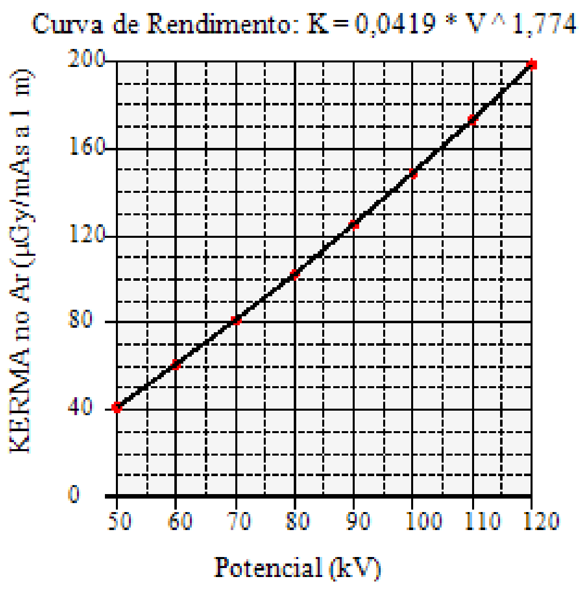



**Figure 3. Potential x air kerma.**

In this yield curve the software has used the average spectral energy of 51,6 keV generating air kerma values formulated in:

$$K = 0{,}0419 \text{ x } V^{1{,}774} \qquad (1)$$

Where K is the air kerma and V the tension. On Fig. 4 is presented the first screen of the software CalDose X v. 4.1

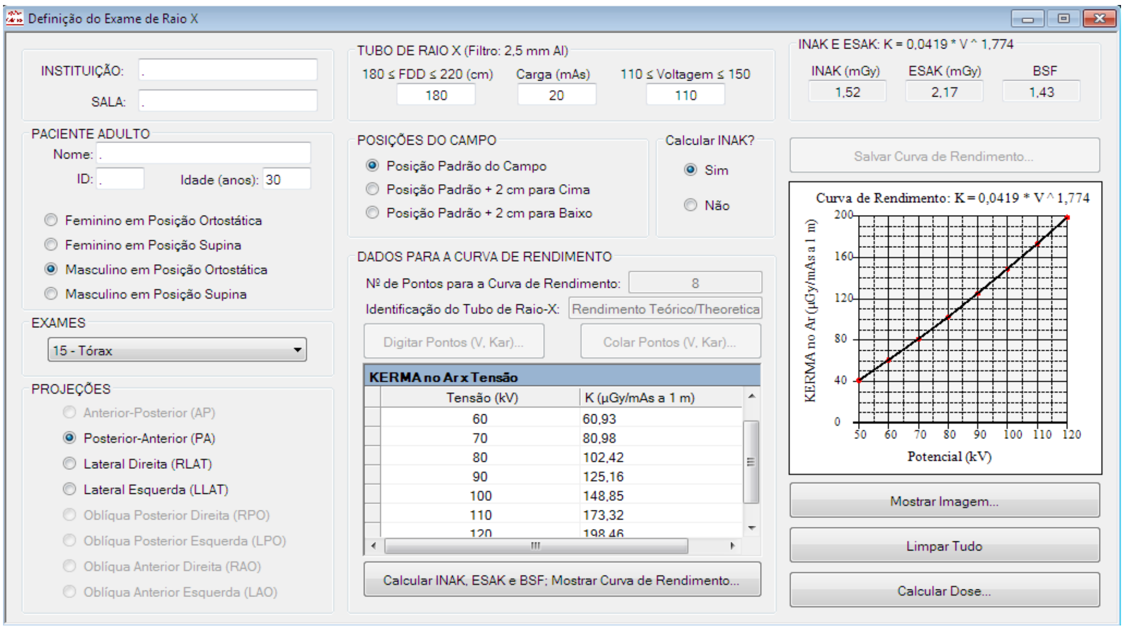



**Figure 4. Screen of software to insert the radiographic techniques parameters.**

On Fig. 4 is presented the screen to insert the parameters as age, genre, projection and incidence, type of exam, tension, applied charge to X-ray tube, focus distance detector (film), positioning of irradiation field in the phantom, data for the generation of yield curve, air kerma, entrance surface air kerma of phantom and backscatter factor.

The software uses the phantom MASH for simulate the adult male patient that has mass of organs, based on ICRP 89 values [7]. The others parameters were repeated in this software.

### 2.3 Simulations with MCNP 4C

On this software was inserted the spectral shown on Fig. 1 using the “si” card, that is the distribution tool of source strength (si) with dots where the probability density distribution (pdf) is defined as A and the probability distribution of emission of this source (sp) due a beam distribution is histogram shape or normal type D. Thus in this simulation was adopted the “si A” and “sp D” cards. In the example below is part of a card of this simulation.

```
mode p
sdef  pos 0 0 -180 erg=D1 dir=d2 vec 0 0 1 par=2
si1 A 0 0.003 0.02 0.03 0.04 0.05 0.058 0.06 0.063 0.065 0.066 0.069
      0.08 0.085
sp1 D 0 10 50 295 400 335 256 645 855 260 170 375 180 50
si2 0.975 1
sp2 0 1
phys:p  20 0 0 $ ver explicacao pag 3-117
prdmp  1000000 1000000
c    print  110
imp:p 1 53r 0 1
m3    7014 .8 8016 .2 gas=1              $air
m4    1001 .105 6000 .414 7014 .034 8016 .439 15031 .001 16032 .002
      17000 .002 19000 .002 26000 .001    $soft tissue
m5    1001 .060 6000 .314 7014 .031 8016 .369 11023 .001 12000 .001
      15031 .070 16032 .002 20000 .152    $bone
c    m6    82000 1.0                     $lead
m7    1001 .1021 6000 .1001 7014 .028 8016 .7596     $lung
c    tallies (flux averaged over cell)
```

In the card above is possible to identify the source of photons (mode p), position and focus-to-detector distance (pos 0 0 -180) and the card “si” (sp1 A and sp1 D).

For generate the statistics error was used $10^9$ photons of energy for packs from 0 to 110 keV with processing time of 140 minutes in a computer 1.8 Ghz processor and 2 GB of Ram.

In this software was utilized the input of phantom MCAT. This MCNP input deck was developed by Sam Yam, Melissa Lambeth and Jacquelyn Yanch of the Massachusetts Institute of Technology, Department of Nuclear Engineering. On Fig. 5 is shown two views of this phantom.

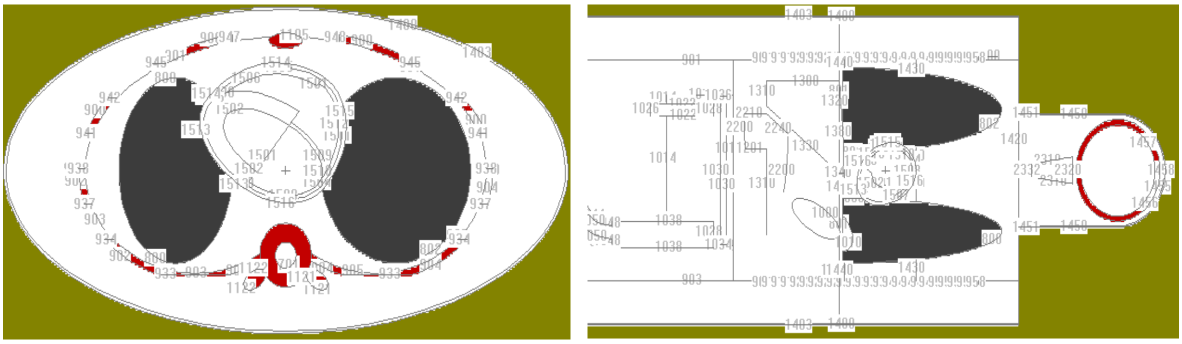
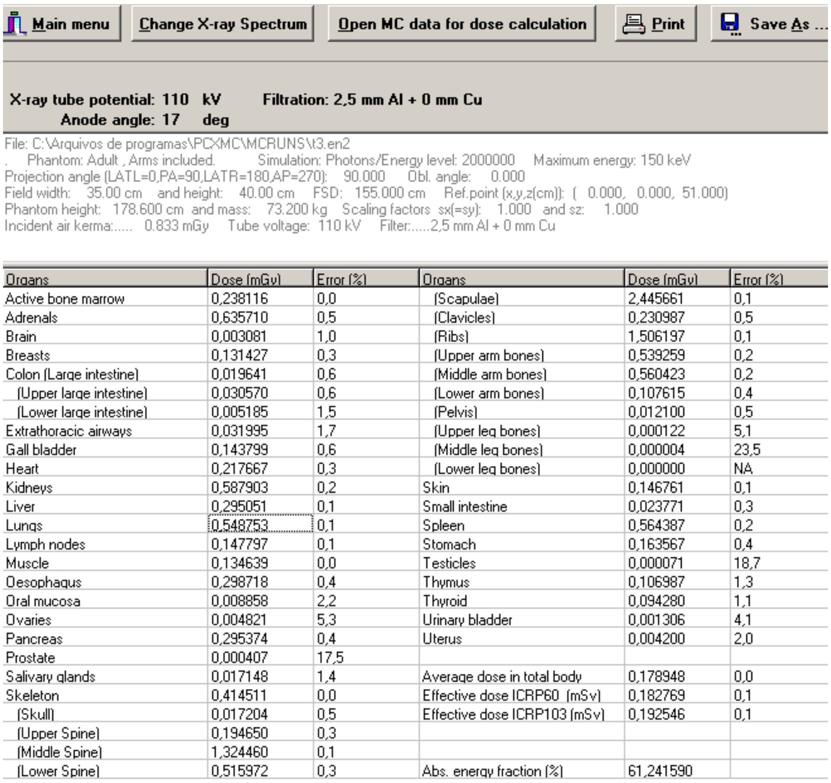


**Figure 5. View coaxial and longitudinal of MCAT phantom.**

## 3. RESULTS

The results of absorbed doses obtained with the PCXMC and the CalDose X provide the results directly on these quantities, as indicated for example on Fig. 6.



Main menu | Change X-ray Spectrum | Open MC data for dose calculation | Print | Save As ...

X-ray tube potential: 110 kV Filtration: 2,5 mm Al + 0 mm Cu
Anode angle: 17 deg

File: C:\Arquivos de programas\PCXMC\MCRUNS\t3.en2
. Phantom: Adult , Arms included. Simulation: Photons/Energy level: 2000000 Maximum energy: 150 keV
Projection angle (LATL=0,PA=90,LATR=180,AP=270): 90.000 Obl. angle: 0.000
Field width: 35.00 cm and height: 40.00 cm FSD: 155.000 cm Ref.point (x,y,z(cm)): ( 0.000, 0.000, 51.000)
Phantom height: 178.600 cm and mass: 73.200 kg Scaling factors sx(=sy): 1.000 and sz: 1.000
Incident air kerma:..... 0.833 mGy Tube voltage: 110 kV Filter:.....2,5 mm Al + 0 mm Cu

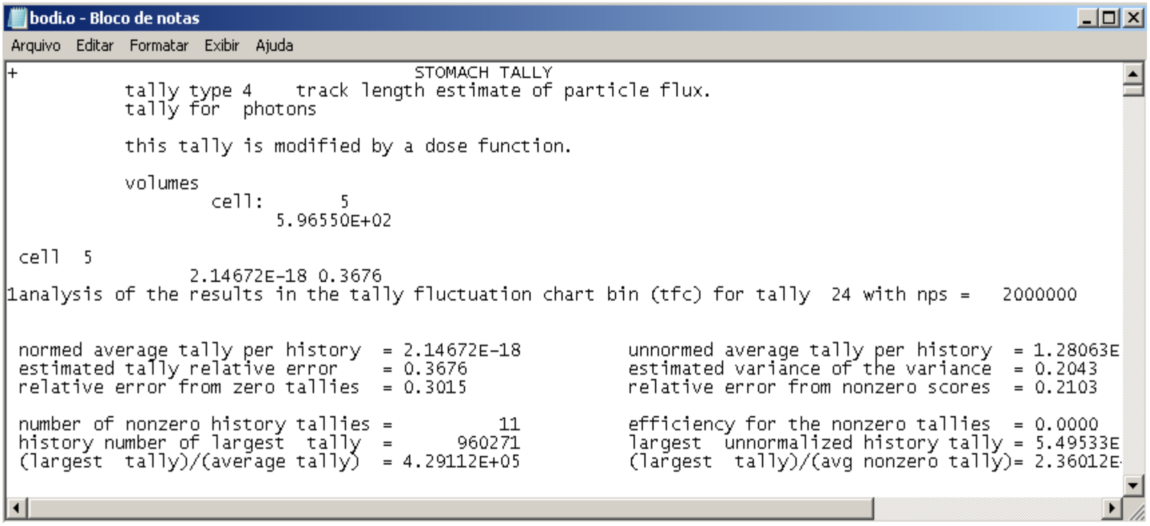
| Organs | Dose (mGy) | Error (%) | Organs | Dose (mGy) | Error (%) |
|---|---|---|---|---|---|
| Active bone marrow | 0,238116 | 0,0 | (Scapulae) | 2,445661 | 0,1 |
| Adrenals | 0,635710 | 0,5 | (Clavicles) | 0,230987 | 0,5 |
| Brain | 0,003081 | 1,0 | (Ribs) | 1,506197 | 0,1 |
| Breasts | 0,131427 | 0,3 | (Upper arm bones) | 0,539259 | 0,2 |
| Colon (Large intestine) | 0,019641 | 0,6 | (Middle arm bones) | 0,560423 | 0,2 |
| (Upper large intestine) | 0,030570 | 0,6 | (Lower arm bones) | 0,107615 | 0,4 |
| (Lower large intestine) | 0,005185 | 1,5 | (Pelvis) | 0,012100 | 0,5 |
| Extrathoracic airways | 0,031995 | 1,7 | (Upper leg bones) | 0,000122 | 5,1 |
| Gall bladder | 0,143799 | 0,6 | (Middle leg bones) | 0,000004 | 23,5 |
| Heart | 0,217667 | 0,3 | (Lower leg bones) | 0,000000 | NA |
| Kidneys | 0,587903 | 0,2 | Skin | 0,146761 | 0,1 |
| Liver | 0,295051 | 0,1 | Small intestine | 0,023771 | 0,3 |
| Lungs | 0,548753 | 0,1 | Spleen | 0,564387 | 0,2 |
| Lymph nodes | 0,147797 | 0,1 | Stomach | 0,163567 | 0,4 |
| Muscle | 0,134639 | 0,0 | Testicles | 0,000071 | 18,7 |
| Oesophagus | 0,298718 | 0,4 | Thymus | 0,106987 | 1,3 |
| Oral mucosa | 0,008858 | 2,2 | Thyroid | 0,094280 | 1,1 |
| Ovaries | 0,004821 | 5,3 | Urinary bladder | 0,001306 | 4,1 |
| Pancreas | 0,295374 | 0,4 | Uterus | 0,004200 | 2,0 |
| Prostate | 0,000407 | 17,5 | | | |
| Salivary glands | 0,017148 | 1,4 | Average dose in total body | 0,178948 | 0,0 |
| Skeleton | 0,414511 | 0,0 | Effective dose ICRP60 (mSv) | 0,182769 | 0,1 |
| (Skull) | 0,017204 | 0,5 | Effective dose ICRP103 (mSv) | 0,192546 | 0,1 |
| (Upper Spine) | 0,194650 | 0,3 | | | |
| (Middle Spine) | 1,324460 | 0,1 | | | |
| (Lower Spine) | 0,515972 | 0,3 | Abs. energy fraction (%) | 61,241590 | |

**Figure 6. Screen of PCXMC results**

On MCNP 4C the results are not presented on the magnitude absorbed dose but in flow. Thus was used the conversion recommended by the ICRP 21 [8]. On Fig. 8 is indicated the result of the flow “cell 5 – 2.14672 $10^{-18}$”. The conversion uses the value of energy generated due the applied tension on R-ray tube and the conversion factor stated on EQUATION 2.

$$E\ (MeV) = (0{,}01\ Gy/h)/(p/cm^2.\ s) \qquad (2)$$

Where E is the energy in MeV, Gy magnitude Gray, h is the time of exposition of phantom and $p/cm^2.s$ is the quantity of photons generated by $cm^2$ in 1 second in focus-to-detector distance.




```
+                                   STOMACH TALLY
         tally type 4    track length estimate of particle flux.
         tally for  photons

         this tally is modified by a dose function.

         volumes
                cell:        5
                     5.96550E+02

 cell  5
              2.14672E-18 0.3676
1analysis of the results in the tally fluctuation chart bin (tfc) for tally  24 with nps =   2000000


 normed average tally per history  = 2.14672E-18          unnormed average tally per history  = 1.28063E
 estimated tally relative error    = 0.3676               estimated variance of the variance  = 0.2043
 relative error from zero tallies  = 0.3015               relative error from nonzero scores  = 0.2103

 number of nonzero history tallies =          11          efficiency for the nonzero tallies  = 0.0000
 history number of largest  tally  =      960271          largest  unnormalized history tally = 5.49533E
 (largest  tally)/(average tally)  = 4.29112E+05          (largest  tally)/(avg nonzero tally)= 2.36012E
```

**Figure 7. Results screen of MCNP 4C.**

The results founded in the three software are presented on TABLE 1.

**TABLE 1 – Obtained results on the Simulations**

| Organ | Software | | | | | |
|---|---|---|---|---|---|---|
| | PCXMC (mGy) | E* (%) | MCNP 4C (mGy) | E* (%) | CalDose X (mGy) | E* (%) |
| Lungs | 0,55 | 0,1 | 0,58 | 3,26 | 0,58 | 0,22 |
| Stomach | 0,16 | 0,4 | 0,19 | 0,37 | 0,18 | 1,15 |
| Thyroid | 0,09 | 1,1 | 0,13 | 21,5 | 0,30 | 2,45 |

*- Statistic error

## 4. CONCLUSION

According to the producer recommendations, to utilize the PCXMC is not indicated to use the charge value applied on R-ray tube, since there no benefits for the precision of results. However even following these recommendations the absorbed doses are close between the three software.

On the PCXMC simulation was used 20 mA.s generating an air kerma of 0,7355 mGy, while, on CalDose X, generate, by spectra, 1,52 mGy as shown on Fig. 3.

The absorbed doses are statistically close, shows that these software generate others procedures to make their results.
The results of the thyroid do not have a regular among the three software. This is because the difference in positioning of the radiation field size, the center of the field considered is the flexibility of adjusting the field size in relation to the trunk and thyroid.

As indicated on results screen of CalDose X the average value used for the spectra energy was 51,6 KeV, returning the indication that to compose the results, utilize also others parameters.

This work has studied three organs, but reproduce a bigger reliability in the use of software PCXMC and CalDose X is necessary to study a larger number of bodies which will be presented in future work.

Due the processing time and hardware, the MCNP 4C is not the best option for determine absorbed doses in patient of diagnostics X-rays, however is an important tool for validate other software for this purpose. The others two software are useful for the improvement of X-ray teams and trainings in a fast and reliable ways, as they has no need of sophisticated hardware.

## ACKNOWLEDGMENTS

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