

Calculation of Neutron Kerma in Tissues

Héctor René Vega-Carrillo

*Unidades Académicas de Estudios Nucleares, Ing. Eléctrica y Matemáticas
Universidad Autónoma de Zacatecas
Apdo. Postal 336, 98000 Zacatecas, Zac. México
rvega@cantera.reduaz.mx*

Eduardo Manzanares-Acuña

*Unidad Académica de Estudios Nucleares
Universidad Autónoma de Zacatecas
Apdo. Postal 336, 98000 Zacatecas, Zac. México
emanz@cantera.reduaz.mx*

Abstract

Neutron kerma of normal and tumor tissues has been calculated using the tissues' elemental concentration. A program developed in Mathcad contains the kerma factors of C, H, O, N, Na, Mg, P, S, Cl, K, etc. that are in normal and tumor human tissues. Having the elemental composition of any human tissue the neutron kerma can be calculated. The program was tested using the elemental composition of tumor tissues such as sarcoma, melanoma, carcinoma and adenoid cystic, also neutron kerma for adipose and muscle tissue for normal adult was calculated. The results are in agreement with those published in literature. The neutron kerma for water was also calculated because in some dosimetric calculations water is used to describe normal and tumor tissues. From this comparison was found that at larger energies kerma factors are approximately the same, but energies less than 100 eV the differences are large.

1. INTRODUCTION

In radiation protection neutron dosimetry has become an important issue because the use and application of neutrons in different areas. Neutrons are obtained from nuclear reactors, accelerators or isotopic neutron sources. These particles are used in different areas such as, solid state physics, material science, chemical analysis, nuclear physics and neutron therapy [1].

Although there are on going several research projects to treat cancer, radiotherapy with photon and electron beams is still the most diffused procedure to control and eliminate tumor diseases [2, 3]. The patient is therefore exposed to an undesirable radiation composed of secondary Compton, pair production and bremsstrahlung secondary photons, as well as to direct and reflected neutrons, which produce a non-negligible dose [4]. These neutrons are produced through (γ, n) reactions between the hard x-rays and the nuclei in the accelerator head, treatment room and the patient body.

To estimate the radiation dose in human body exposed to external sources a set of simple specifications of mass, dimensions, and elemental composition of the organs and tissues are required [5].

Measurement of the absorbed doses within and around irradiated body tissues necessitates selected materials from which phantoms and radiation detectors are constructed. These materials should be, in density and elemental composition, as close as possible to organs and tissues of human body [6].

Neutron-induced reactions play an important role in the particle transport, radiation effects in accelerator-based systems for transmutation, medicine and material research. Specially, charged-particle production reactions (n, xz), are important to estimate the neutron energy that is transferred to kinetic energy of charged particles per unit mass (Kerma) required for the evaluation of the radiation effects and the nuclear heating [7].

Therefore, to determine the dose deposition is important to know the element concentration of body tissue and tissue substitute. In the case of radiation therapy treatment with photons, electrons, and neutrons this relevance has been discussed in reports published by the International Commission on Radiation Units and Measurements (ICRU) [6, 8].

Kerma factors (quotient of kerma by neutron fluence) sometimes called fluence-to-kerma factors, are useful in neutron dosimetry because absorbed dose measurements are realized with instruments built with tissue-equivalent materials but hardly ever have the exact composition of the tissue in which the kerma or absorbed dose is measured. Thus, if there is some approximate knowledge of the neutron spectrum at the point of measurement, the kerma or absorbed dose in the tissue can be found from the measured kerma or absorbed dose in the instrument. Also, if the neutron spectrum is known at a point of interest, from either measurements or calculations, the kerma is the product of the fluence and the appropriately averaged kerma factor [10].

Particularly ICRU 46 [8] includes composition data of a set of selected organs for several different individuals. However, it does not include relevant data of tumors of different histologies [9].

In this study neutron kerma coefficient for a set of elements important in biology and medicine has been utilized to calculate the neutron kerma factors for different tissues.

2. MATERIALS AND METHODS

A series of kerma factors for elements ($k_f(E)$) were used to calculate the kerma factors for different tissues ($k_T(E)$) using the equation (1).

$$k_T(E) = \sum_i w_i k_f(E)_i \quad (1)$$

here, w_i is the percent composition by weight of i^{th} element in tissue and $k_f(E)_i$ is the kerma factor

of ith element in tissue. Calculated factors were compared with those reported in literature for water, normal body tissues and selected tumors.

Kerma factors in function of neutron energy for elements that are relevant in biology were taken from Caswell et al. [11] In figure 1 are shown kerma factors for C, H, O and N, while in figure 2 kerma factors for Na, Mg, K, and Cl. Kerma factors for B, Al, Si, and P are plotted in figure 3 and in figure 4 the kerma factors for S, Ca, and Fe are shown.

To test the program the elemental composition of sarcoma, melanoma, carcinoma, adenoid cystic, adipose and muscle tissues were calculated. To compare the neutron kerma of tumor and normal tissues the kerma of water was calculated as well. In table 1 the weight fraction of elemental composition of these tissues are shown. These tumor types are histologies, which are known to respond well to neutron therapy.

Table I. Elemental composition of selected tumors and normal body tissues

Tumor or tissue	H [w/o]	C [w/o]	N [w/o]	O [w/o]	Others [w/o]
Carcinoma	10.0	18.5	4.2	65.9	Ash
Sarcoma	10.5	8.1	2.1	78.0	Ash
Melanoma	9.4	21.2	5.6	61.5	Ash
Adipose	11.2	51.7	1.3	35.5	0.1 Na, 0.2 P, 0.3 S, 0.2 Cl, 0.2 K
Muscle	10.2	14.3	3.4	71.0	0.1 Na, 0.2 P, 0.3 S, 0.1 Cl, 0.4 K

3. RESULTS

To calculate kerma factor using equation (1) a program, named Kerma, was developed in Mathcad [12]. This program uses the element's kerma factors and allows determine the neutron kerma factors of any material or tissue providing the element composition by weight percent. In figure 4 and 5 are shown sections of Kerma program. The output of calculated neutron kerma factors are in plots, tables and files.

In figure 7 the neutron kerma factors for tumor tissues of sarcoma and melanoma are shown, in this figure the neutron kerma for normal adult adipose tissue and water are added for comparison.

In figure 8 the neutron kerma factors for tumor tissues of carcinoma and adenoid cystic are shown. Here, the neutron kerma for normal adult muscle tissue and water are added for comparison. In both figures can be noticed that for neutrons with energies less than 10^{-4} MeV there are significant differences in kerma factors, this differences are larger when normal and tumor tissues are compared with water. This is particularly important because to simplify dosimetric calculations tumor and normal tissues are described as water-made.

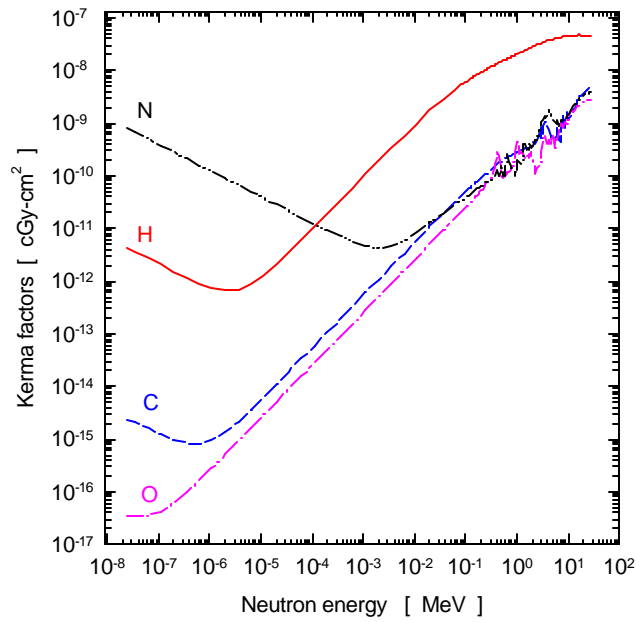


Figure 1. Neutron kerma factors for C, H, O and N.

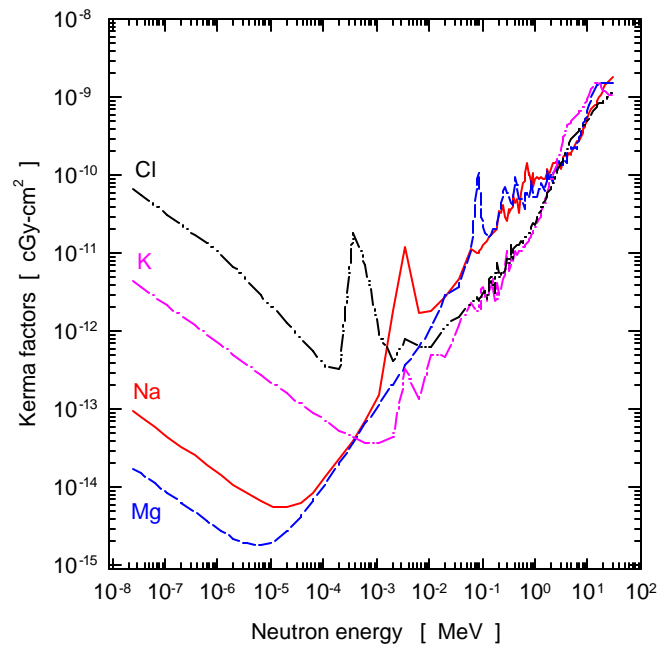


Figure 2. Neutron kerma factors for Cl, K, Na and Mg.

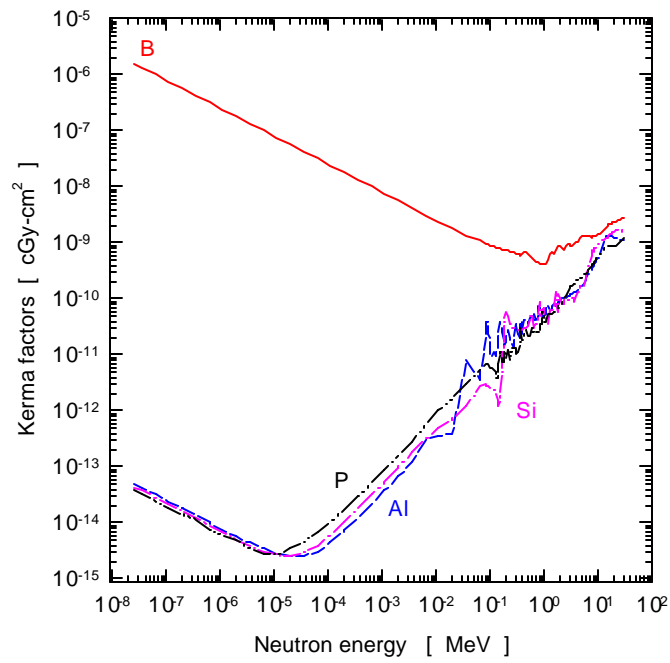


Figura 3. Neutron kerma factors for B, Al, P and Si.

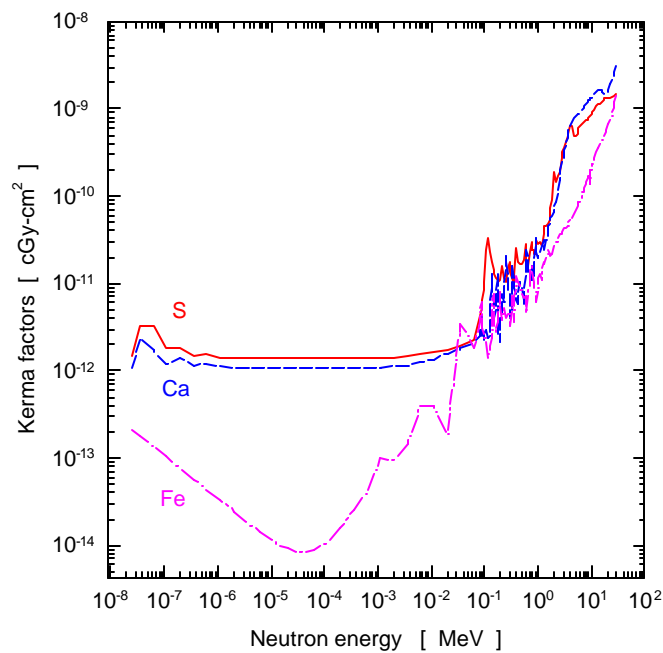


Figura 4. Neutron kerma factors for S, Ca and Fe

File: KERMA.MCD (Ver. 7)
 Date: j/14-FB/2004
 Machine: FOMES98
 File: C:/misdoc/2004/snm/Kermal
 Program: Kerma.mcd

KERMA

KERMA calculations in dose per unit neutron fluence [cGy-cm² = rads-cm²], in differents tissues..

Elemental Kerma factors were obtained from Caswell, R.S., Coyne, J.J. and Randolph, M.L. (1982) *Kerma factors of elements and compounds for neutron energies below 30 MeV* , Int. J. Appl. Radiat. Isot. **33**: 1227-1262.

Procedure was tested against calculations made for different tumoric tissues reported by: Maughan, R.L., Chuba, P.J., Porter, A.T. and Ben-Josef, E. (1997) *The elemental composition of tumors: Kerma data for neutrons* , Med. Phys. **24**(8): 1241-1244.

```
Datos := READPRN "kerma.txt")      E := Datos<0>      H := Datos<1>      B := Datos<2>
C := Datos<3>      N := Datos<4>      O := Datos<5>      Na := Datos<6>      Mg := Datos<7>
Al := Datos<8>      Si := Datos<9>      P := Datos<10>      S := Datos<11>      Cl := Datos<12>
K := Datos<13>      Ca := Datos<14>      Fe := Datos<15>      i := 0.. length(E) - 1
```

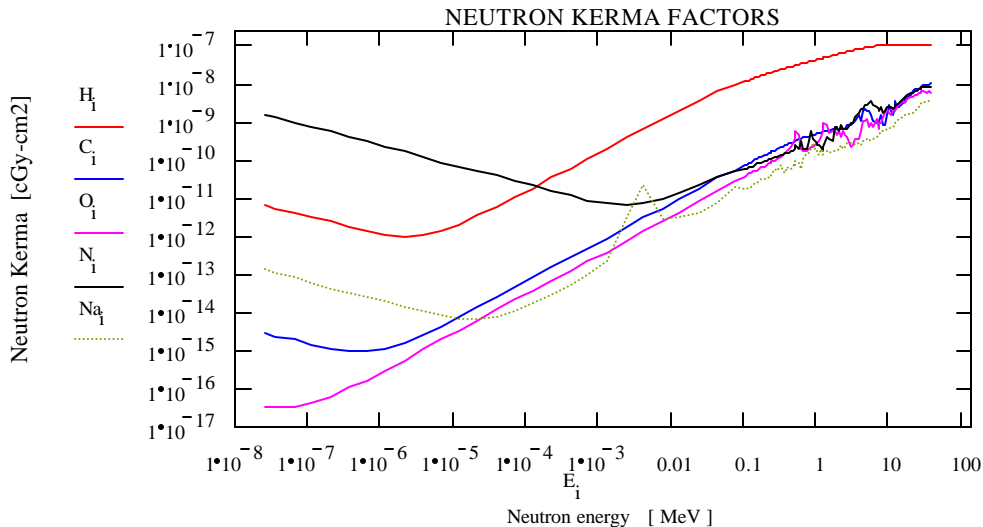


Figure 5. Input data in Kerma program

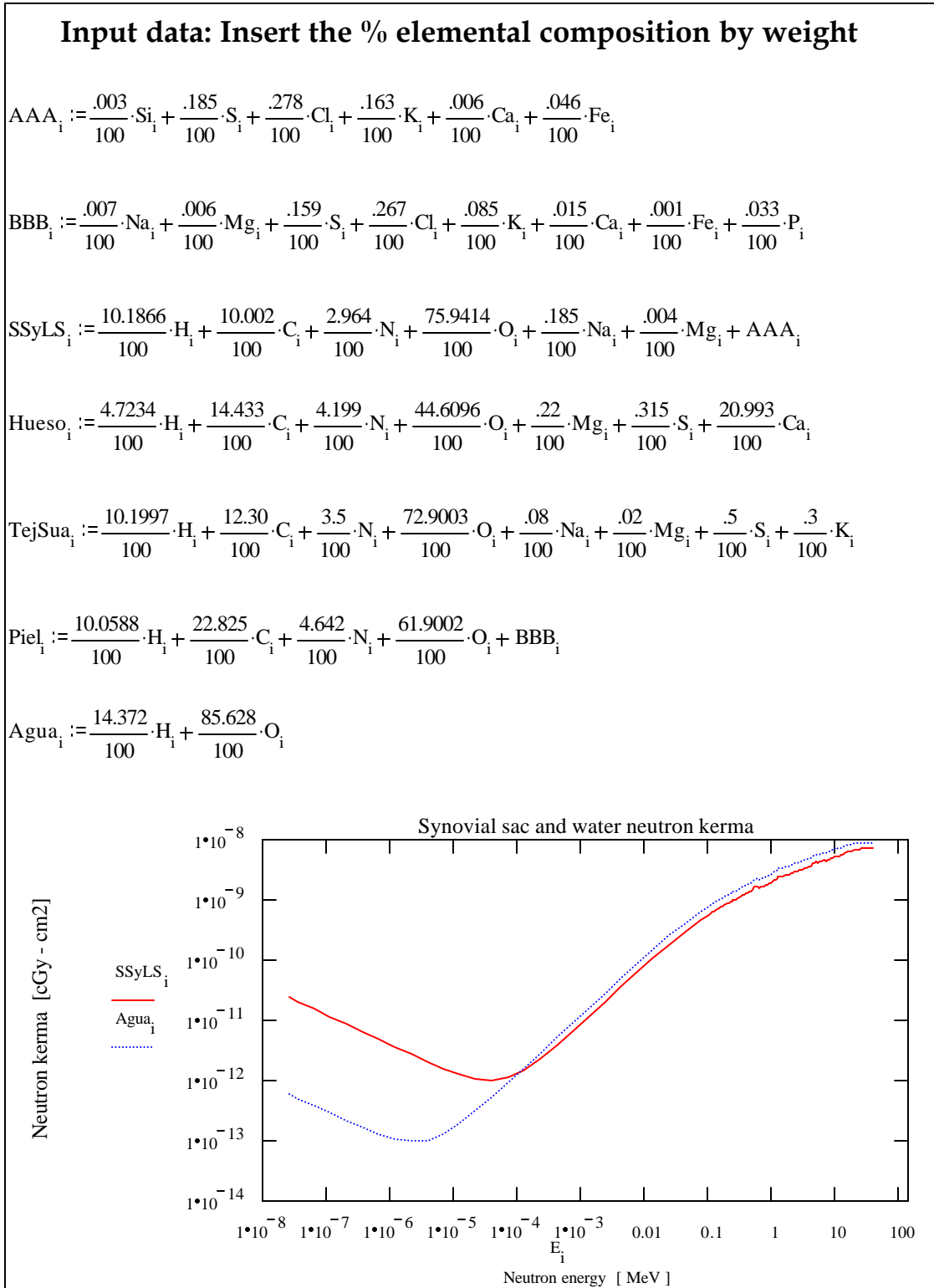


Figure 6. Output data in Kerma program

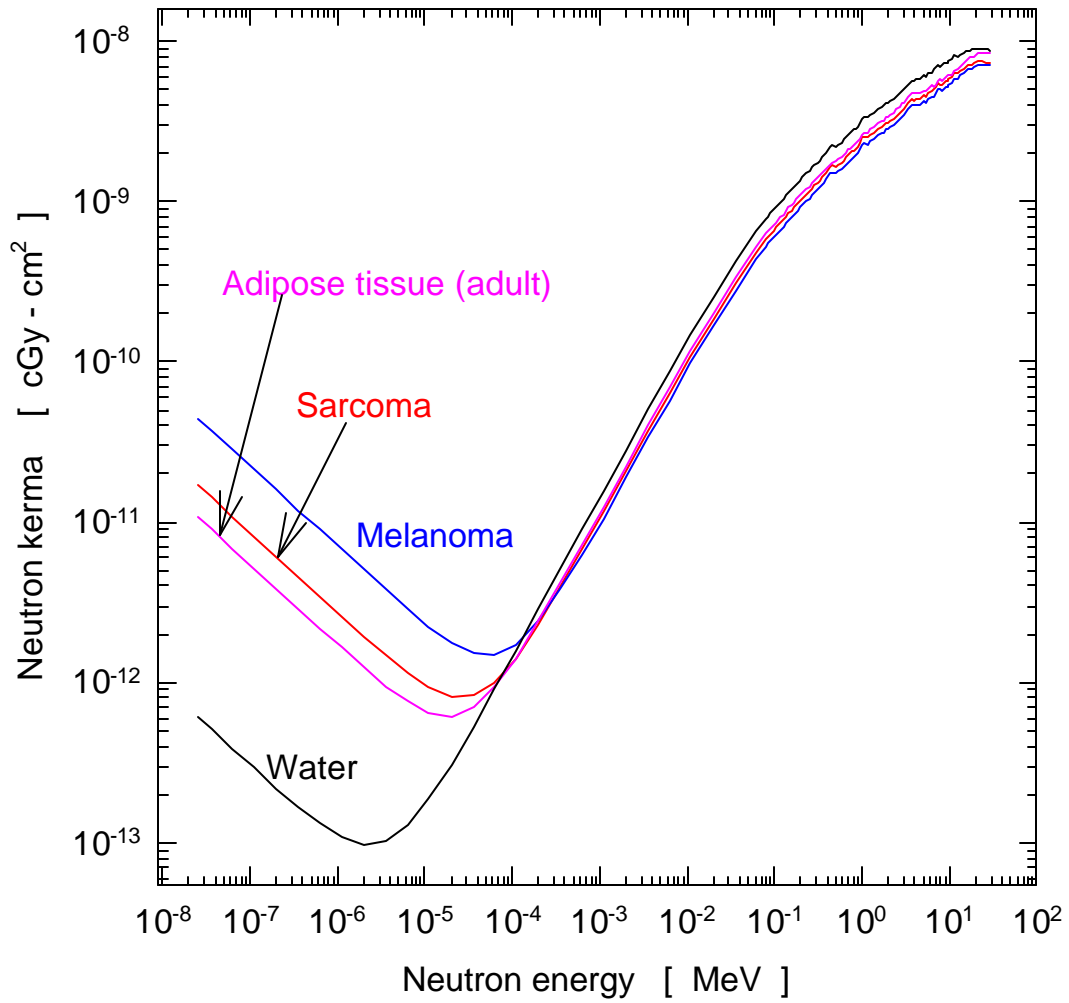


Figure 7. Kerma factors of Sarcoma, Melanoma and Adipose tissues. Neutron kerma in water is added for comparison

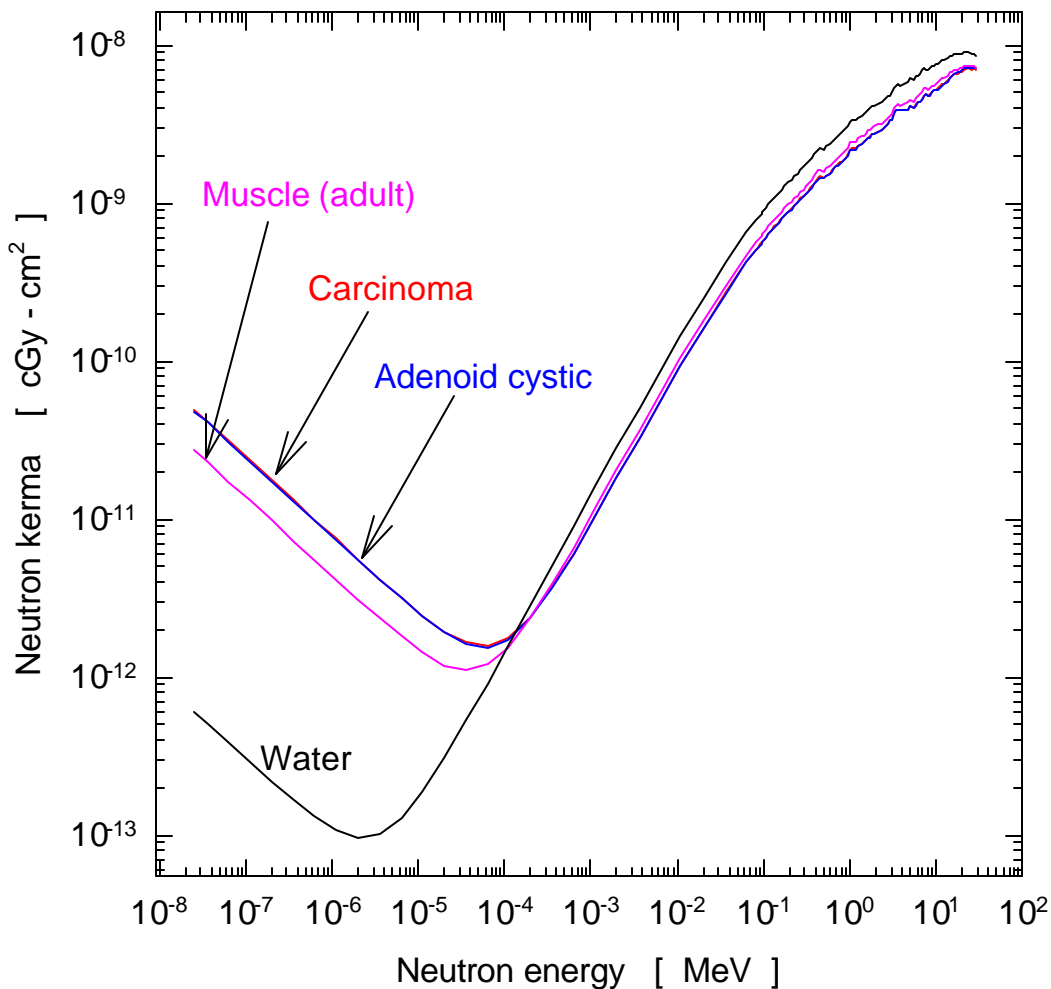


Figure 8. Kerma factors of Carcinoma, Adenoid cystic and Muscle tissues. Neutron kerma in water is added for comparison

4. CONCLUSIONS

Calculated neutron kerma factors for normal and tumor tissues are in agreement with those reported in literature [9].

For fast neutron therapy the energies of interest are between 1 and 70 MeV where differences between neutron kerma of tumor and normal tissues are small, however these differences are large for neutrons with energies less than 100 eV.

During neutron dosimetry is important to know the elemental composition of different tissues exposed to neutrons. This information allows estimate the kerma factors in function of neutron energy. If a neutron spectrum is available neutron kerma can be calculated using the neutron kerma factor of different tissues.

The Kerma program here developed is user friendly and simple to execute. The program can be easily updated if new kerma factors are available or in case the neutron kerma of materials different from human tissues need to be calculated.

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