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PRODUCTION OF ^{125}I FROM AMORPHOUS FILMS OF Si DOPED WITH ^{124}Xe AND EVALUATION OF ITS POTENTIAL USE IN BRACHYTHERAPY.

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ABSTRACT

This work describes the simulation of a new material that can be used in the brachytherapy treatment. The material consists of xenon-incorporated amorphous silicon (Xe@a-Si). The irradiated ^{124}Xe atoms of the samples are converted into ^{125}Xe, according to the reaction: ^{124}Xe (n,γ) ^{125}Xe that, in turn, decays to the radioisotope ^{125}I. A set of simulations performed using the MCNP5 code, shows that, in principle, the material proposed can be used in the seed of brachytherapy in the clinical treatment.

1. INTRODUCTION

Currently, in Brazil the use of treatment with ^{125}I brachytherapy sources is still very limited due to high cost because the material is imported. Currently it makes the use of radionuclides produced artificially as ^{131}Cs,^{192}Ir,^{198}Au,^{125}I and the ^{103}Pd [1-2]. The brachytherapy by permanent implant for the treatment of prostate cancer in contemporary style was introduced in the 1980s with the excellent result, the method prevailed rapidly in the US in the 1990's , and has now become a standard treatment option , at least for low-risk prostate cancer. The goal of prostate brachytherapy is to deliver a lethal dose to the tumor while minimizing the dose to the organs at risk [3-5] .

An important application of xenon-incorporated amorphous silicon (Xe@a-Si) films (or matrices) is on the field of nuclear medicine. The ^{124}Xe atoms can be converted into ^{125}Xe, according to the reaction ^{124}Xe(n, γ)^{125}Xe, that, in turn, decays to the radioisotope ^{125}I, Fig. 1 This radioisotope is employed in brachytherapy, an invasive anticancer radiotherapy technique applied in some types of cancer, e.g., prostate tumors [6]. The set of matrix and cover is named as brachytherapy seed. The ^{125}I has the adequate nuclear properties such as low X– ray energies (27.2 – 31.9 keV), low gamma energy (35.5 keV), and half-life of 59.4 days, to be employed in the brachytherapy. The Figure 1 shows the gamma spectra of the ^{125}Xe radioisotope and the decay scheme of ^{125}Xe to ^{125}I. The proposed seed is composed of a cylindrical ^{124}Xe@a-Si matrix of 5 mm length and of 0.8 mm of diameter covered by a Ti capsule of 0.7 mm thick [6].

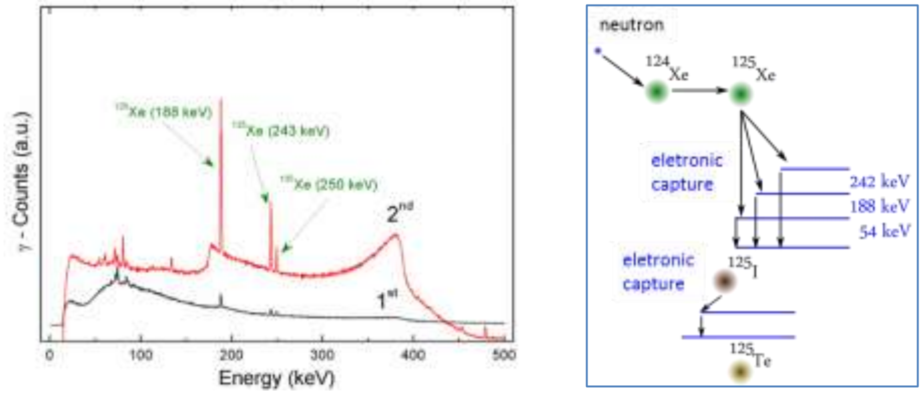

Figure 1: Spectra of ^{125}Xe after two counting times (left). Decay scheme of ^{124}Xe and production of ^{125}I.

In a previous work, it has been shown that an activity up to 1,0 mCi could be achieved if standard radiation conditions found in many nuclear reactors worldwide is used. In this work, a set of matrices of Si films were doped with ^{124}Xe were irradiated to evaluate the potential of using the resulting radionuclide ^{125}I in brachytherapy seeds. The results showed that, in principle, clinical dose can be reached with Si films doped with Xe atoms in concentrations higher than 5% a.t.

2. MATERIALS AND METHODS

The code MCNP (Versions 5 and X) were used for evaluating the preliminary model of the system and to perform the calculations of the neutron flux in the inclined tube. The calculations reported in this paper were performed with version 5.1.40 of the code and with the ENDF/B-VII.0 cross section library (processed at the National Nuclear Data Centre at Brookhaven, obtained from the Radiation Safety Information Computational Centre at Oak Ridge), [7], Fig. 2.

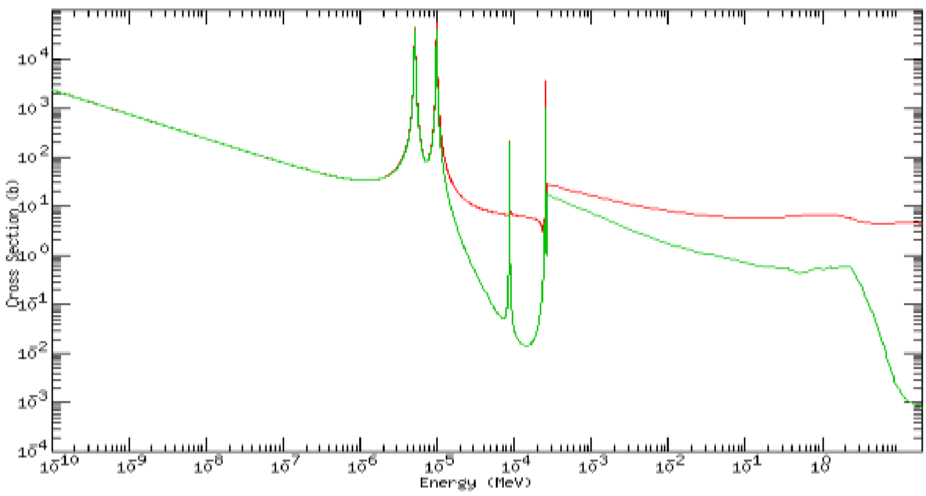

Figure 2: Cross section for isotope ^{124}Xe. Red: total, Green capture [8]

The thermal, (E < 0.625 eV), and epithermal (E < 100 keV) components of the neutron flux were calculated and compared with experimental results in order to validate and adjust the model of the system. Fast neutrons (E > 100 keV) were not investigated. In this work, the MCNP was set to 2.5 × 10^4 histories and 5700 cycles were used. The software run in a Core Duo 22,5GHz processor with 50h of processing time, in average.

3. RESULTS AND DISCUSION

The seeds were simulated as being formed by a Si doped cylinder with ^{124}Xe 5.00 mm long with 0.08 mm diameter, covered by a tungsten cylinder 5.20 mm long, 0.10 mm diameter and 0.07 mm thick. These seeds were inserted in a cylindrical radiating radius of 1.86 cm and 8.78 cm. In this irradiator, the seeds were arranged in a square array with distances between seeds (center to center) of 3.0 mm. This matrix was replicated 8 times, 9 formed with an irradiating layers 10,00 mm thickness each. In each layer, 113 seeds were accommodated with a total of 1017 seeds. The irradiator was positioned in the central position of the reactor core for producing an estimated ^{125}Xe, 125 precursor, by irradiating the seeds, Figs (3-5).

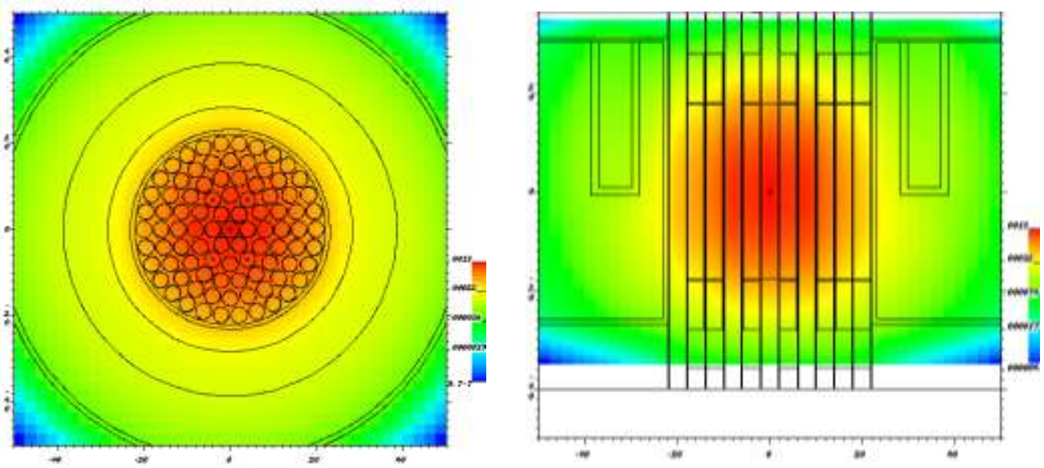

Figure 3: Mapping of the neutron flux in the TRIGA reactor: horizontal plan (left) and vertical plan (right).

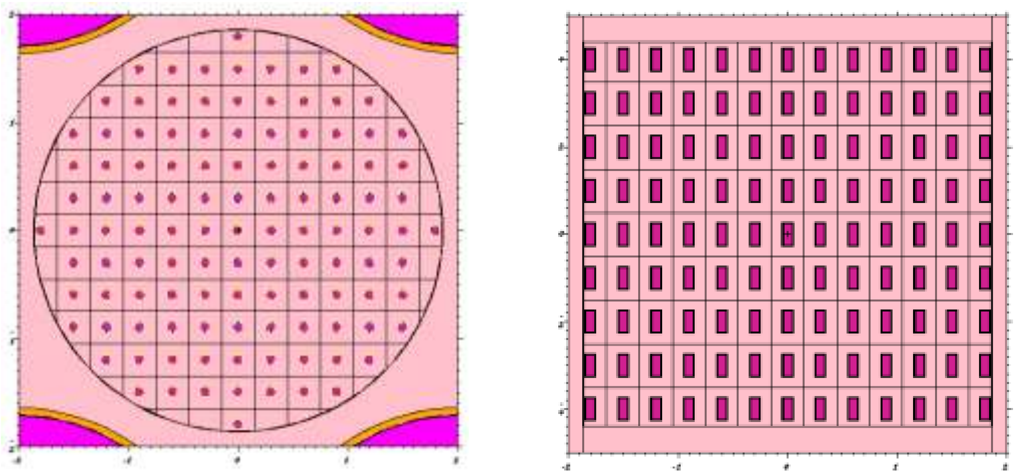

Figure 4: Geometry of the cylindrical irradiator used in the MCNP: horizontal plan (left), axial plan (right).

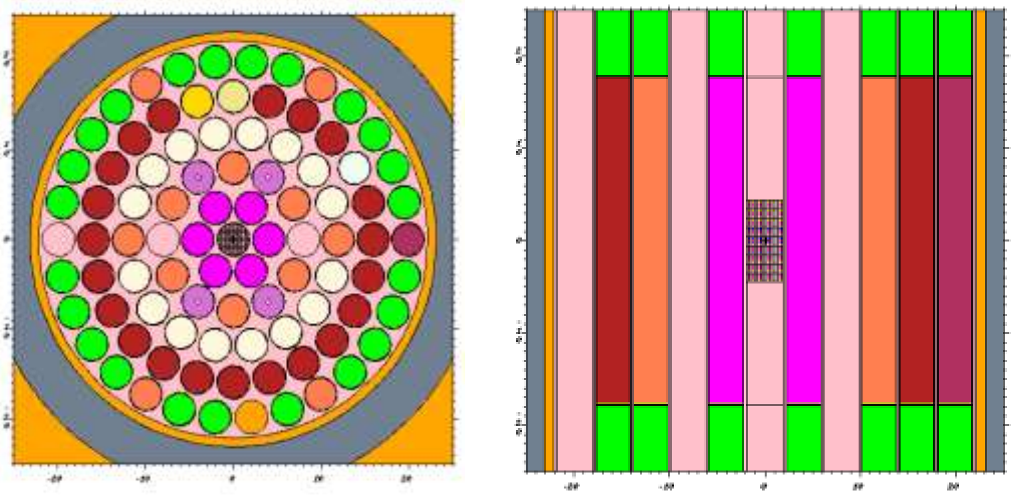

Figure 5: Position of the cylindrical irradiator used in the MCNP: horizontal plan (left) axial plan (right)

Table 1 shows the composition of the seeds for the three cases considered. Each case corresponds a different concentration of ^{124}Xe.

Table 1: Composition specification of doped Si seed with ^{124}Xe for each case considered.

Element	A	Case 1		Case 2		Case 3	
		at.(%)	mass (%)	at.(%)	mass (%)	at.(%)	mass (%)
Si	28	4.79E-1	4.33E-1	4,67E-1	3,92E-1	4,85E-1	4,56E-1
	29	4.79E-1	4.48E-1	4,67E-1	4,06E-1	4,85E-1	4,73E-1
	30	1.61E-2	1.56E-2	1,57E-2	1,41E-2	1,63E-2	1,64E-2
Xe	124	2.60E-2	1.04E-1	5,06E-2	1,88E-1	1,32E-2	5,48E-2

The calculated reactivity coefficients were always positive (above 3,000 pcm), probably as a reflection of the complete exclusion of the control rods and safety of simulated geometry. It is important to consider that the results of MCNP are normalized in the case of critical systems, the number of fissions which, in turn, dependent upon reactor operation power. The following factors were also considered: 200 MeV/fission; 1.6021773 x 10^{-13}J/MeV and the reactor power operation of 100kW.

Table 2 shows the characteristics of the seeds:

Table 2: Physical specification of doped Si seeds with ^{124}Xe for each case considered.

Case	Volume (cm^3)	Mass (g)	Density	
			Gravimetric ($g.cm^{-3}$)	Atomic ($atoms.b^{-1}.cm^{-3}$)
1	2,51327E-03	5,52920E-03	2,200	4,27664E-2
2				3,97488E-2
3				4,45232E-2

The Table 3 shows the results for average neutron flux for each case considered

Table 3: Calculated results of the average neutron flux for the seeds.

Case	Results MCNP ($cm^{-2}.fission^{-1}$)	Neutron Flux ($cm^{-2}.s^{-1}$)
1	1,31884 (0,08%)	4,047 x10^{11}
2	1,29602 (0,08%)	3,977 x10^{11}
3	1,33554 (0,08%)	4,098 x10^{11}

It is important to mention that the MCNP calculates the flow through the ratio between average path in the cells by the volume of cells. The volume considered was the only one cell. Table 4 shows the reaction rate and the production of ^{125}Xe atoms and the activity (dps) considering an irradiation time of 8h.

Table 4: Calculated results of neutron capture rate for the ^{124}Xe present in the seeds for each case considered.

Case	Results MCNP (1M -2) (reactions of capture.fission^{-1})	Production of de ^{125}Xe (s^{-1})
1	1,3 x 10^2 (0,24%)	4,7 x10^8
2	1,2 x 10^2 (0,19%)	7,2 x10^8
3	1,4 x 10^2 (0,29%)	2,6 x10^8

Using the data from the Table (4) for a time of irradiation of 8h and the equation (1), the activity of the ^{125}I can be calculated.

$$A_I(t) = A_0^{Xe} \frac{\lambda_I}{\lambda_{Xe} - \lambda_I} e^{-\lambda_{Xe} t}(1 - e^{-(\lambda_I - \lambda_{Xe})t}) + A_0^I e^{-\lambda_I t} \quad (1)$$

In this simulation, if a concentration of ^{124}Xe is considered as 100%, an activity higher than 1,0mCi, normally the value used in clinical application of brachytherapy, could be obtained. Just to compare, considering an hypothetic situation of a neutron flux of 10^{14} $cm^{-2}s^{-1}$, irradiation time of irradiation of 50h and taking the half –lives of the ^{125}Xe and ^{125}I, respectively, as 16.4h and 60days, after one week of decaying, an activity of ^{125}I of ~40MBq ≅ 1,1mCi can be obtained.

4. CONCLUSION

In these work, the irradiation of a model of seed to be used in brachytherapy treatment based on films of amorphous Si doped with ^{124}Xe atoms calculated using the MCNP code. The results showed that under standard conditions of irradiation available in many research reactors worldwide, activity of ~ 1,0mCi of ^{125}I after the decay of the ^{125}Xe could be obtained. This result can represent a good perspective for a cheaper alternative for brachytherapy enhancing its access to the population.

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