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Original Article

FEASIBILITY STUDY FOR PRODUCTION OF IODINE-131 USING DIOXIDE OF TELLURIUM-130

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ABSTRACT

Objective: Currently, nuclear medicine is becoming increasingly important, through the discovery of several medical radioisotopes, which are used in diagnosis, treatment, and medical imaging. Among the most important radionuclide which is commonly used is iodine-131, with a half-life of 8.02 d. Iodine-131 is one of the mainly essential elements in nuclear medicine. Since their first use, several studies have been conducted to meet the world need of hospital specialists in nuclear medicine. The purpose of this study was to participate in a lawsuit about the feasibility of producing ^{131}I.

Methods: using neutron activation of the dioxide of tellurium (TeO_2) under a neutron flux which varies between 5 10^{11} and 10^{13} n/cm²s for 4, 6 and 8 hours** per irradiation cycle during 5 d, and used the Fortron90 Code to calculate the activity of iodine-131.

Results: The result of the activity of iodine-131 found about 4,634 Curie with an irradiation of 4 hours** per day and 9.381 Curie with an activation of 8 hours** per day.

Conclusion: Production of iodine-131 can be very effective if an acceptable capsule is used for different masses of tellurium and a neutron flux in a nuclear reactor.

Keywords: Iodine-131, Tellurium, Neutron activation, Thyroid, Cancer, Nuclear medicine, Becquerel

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INTRODUCTION

Radioisotopes used for many years in many fields of medicine [1-14], industry [15], food and science, [16-17]. Accelerators and nuclear reactors are frequently used for the production of radioisotopes, at the moment, the demand for medical isotopes increases, such as iodine-131, [18-32], but it raises problems of cost and transportation of the producer country to consumer countries, which requires a new strategy for countries who had research reactors to produce iodine-131 [33], Such as Morocco, which has personal skills, researchers and academics in the nuclear field. Furthermore, Morocco is also a well-developed infrastructure which uses the nuclear research reactor TRIGA-MARC II 2-MW installed at the National Centre of Energy and Science and Nuclear Techniques in Rabat (CNESTEN). This facility meets the global regulatory requirements, nuclear safety, radiation protection and environmental protection. At this time, some studies are made to the feasibility of the production ^{131}I, B. El Bakkari [34], A. S. Elom Achoribo [35], O. Yu. Kochnov [36], M. A. El-Absy [37], D. IAEA CDOC[38]. There are two main methods for the production of ^{131}I, the first way is the fission of ^{235}U [36] and the second way is a nuclear reaction (1) of 13 °Te, the last method is the one which attracts my interest.

$$ {}^{130}_{52}Te + {}^{1}_{0}n \rightarrow {}^{131}_{52}Te + \gamma \rightarrow {}^{131}_{53}I + {}^{0}_{-1}e + \gamma \text{ .... (1)} $$

With $t_{1/2}(^{131}Te)$= 25 min and $t_{1/2}(^{131}I)$=8.02 d

Research reactors cannot function for a long time because they should be stopped sporadically to make them cold, so a discontinuous operation is obligatory for the production of iodine-131. We call it cyclical irradiation, [40-42]. It is an irradiation of samples for a moment which can take hours. After the shutdown of the irradiation for some hours; we repeat this method for many cycles until the attainment of our objective.

The main aim of this theoretical study was to search the feasibility of producing ^{131}I. We are interested in a range of neutron flux in the channel of irradiation from 5 10^{11} to 10^{13} n/cm²s which is generated by research nuclear reactor and capsulated targets of TeO_2, with the mass from 1 g to 150 g. By using an analytical method and the cyclic neutron activation technical, we calculate the following activities of 4, 6 and 8 hours** of irradiation per day to achieve our goal.

METHODS AND MATERIALS

Production of-131

Productions of iodine-131 are generated by the following equation,

$$ \frac{dN({}^{131}_{53}I)}{dt} = \sigma({}^{130}_{52}Te)\varphi N({}^{130}_{52}Te)\left(1 - e^{-\lambda({}^{131}_{52}Te)t}\right) - \lambda({}^{131}_{53}I)N({}^{131}_{53}I) $$

.... Equation 1

With,

σ Cross section microscopic (barn)

φ Neutron fluxes n/cm²s

λ Radiative constant h^{-1}

At t=0 are found that $N({}^{131}_{53}I) = N({}^{131}_{52}Te) = 0$

By integrating equation 1 can give the number of formal's core in each irradiation cycle which is in Equation 2, [34] [36][43-48].

$$ N({}^{131}_{53}I) = \sigma({}^{130}_{52}Te)\varphi N({}^{130}_{52}Te)\left(\left(\frac{1-e^{-\lambda({}^{131}_{53}I)t_{irrad}}}{\lambda({}^{131}_{53}I)} + \frac{e^{-\lambda({}^{131}_{52}Te)t_{irrad}} - e^{-\lambda({}^{131}_{53}I)t_{irrad}}}{\lambda({}^{131}_{52}Te)-\lambda({}^{131}_{53}I)}\right) e^{-\lambda({}^{131}_{53}I)t_{decay}} + \frac{\left(1-e^{-\lambda({}^{131}_{52}Te)t_{irrad}}\right)\left(e^{-\lambda({}^{131}_{52}Te)t_{decay}} - e^{-\lambda({}^{131}_{53}I)t_{decay}}\right)}{\lambda({}^{131}_{53}I)-\lambda({}^{131}_{52}Te)} $$

...... Equation 2

Or t_{irrad}: Irradiation time

t_{decay}: Decay time at the end of irradiation.

And $N({}^{130}_{52}Te) = \frac{m({}^{130}_{52}Te)N_a}{M({}^{130}_{52}Te)}$ .... Equation 3

$m(^{130}Te)$=6.02 10^{23} mol^{-1}, Avogadro's number;

$m(^{130}Te)$ the weight in grams of tellurium;

$M(^{130}Te)$ the atomic mass of irradiated Telluriem isotope.

We can extract activity of ^{131}I in each irradiation cycle using equation 4

$$A(^{131}_{53}I) = \lambda(^{131}_{53}I)\, N(^{131}_{53}I) \text{ .... Equation 4}$$

With A activity by Curie,

As it was motioned at the beginning of the irradiation (^{130}Te) in the form of a cyclic radiation from each study, with 4, 6 and 8 hours** respectively per day for 5 d, the fig. 1 explains the steps of irradiation in each cycle.

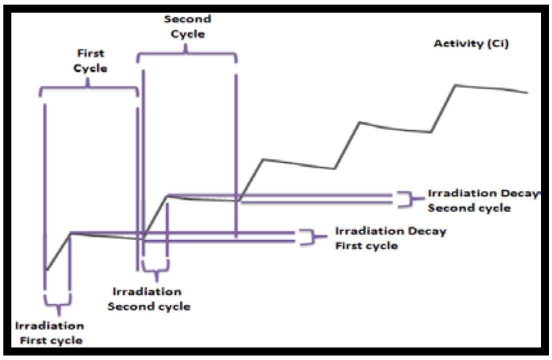

Fig. 1: Evolution of activity with a cyclic irradiation

By accumulation of activity for each cycle is,

For the 1st cycle:

$$A(\text{cycle } 1) = A_{\text{irrd time of first cycle}}(^{131}_{53}I) - A_{\text{decay (8h to 24h) of first cycle}}(^{131}_{53}I)$$

For the 2nd cycle:

$$A(\text{cycle } 2) = A(\text{cycle } 1) + A_{\text{irrd time of second cycle}}(^{131}_{53}I) - A_{\text{decay time of second cycle}}(^{131}_{53}I)$$

For the 3rd cycle:

$$A(\text{cycle } 3) = A(\text{cycle } 2) + A_{\text{irrd time of third cycle}}(^{131}_{53}I) - A_{\text{decay time of third cycle}}(^{131}_{53}I)$$

For the 4th cycle:

$$A(\text{cycle } 4) = A(\text{cycle } 3) + A_{\text{irrd time of fourth cycle}}(^{131}_{53}I) - A_{\text{decay time of fourth cycle}}(^{131}_{53}I)$$

For the 5th cycle:

$$A(\text{cycle } 5) = A(\text{cycle } 4) + A_{\text{irrd time of fifth cycle}}(^{131}_{53}I) - A_{\text{decay time of fifth cycle}}(^{131}_{53}I)$$

Finally, we found the global activity of ^{131}I,

After the final calculation, the results obtained are shown schematically in the form of figures.

RESULTS AND DISCUSSION

From the simulations obtained in five irradiation cycles for each cycle with 4, 6 and 8 hours** of irradiation in a neutron flux 5 10^{11}, 10^{12}, 5 10^{12} and 10^{13}n/cm²s, we have observed clearly that the activity increases during 4, 6 and 8 hours**.

After the stoppage of the first irradiation, the activity decreases slightly in the hours after (radioactive decay of Iodine-131). When we start the second cycle, the activity increases in the irradiation period and it decreases in the cooling period.

This process continues to increase and decrease until the end of the fifth round to achieve the maximum activity, fig. from 4 to 15 show the variation of the activity of ^{131}I at different target weights (5g, 10g, 30g, 50g, 100g and 150g) and attached to a neutron flux ranges from 5 10^{11} to 10^{13} n/cm²s, for irradiation time 4, 6 and 8 hours** in each cycle. This work was well validated with the study of A. S. Elom Achoribo [35] and B. El Bakkari [34].

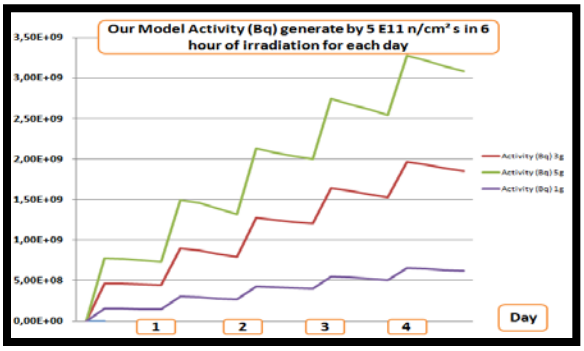

Fig. 2: Validation of our model, evolution of activity (Bq) in 6h of irradiation in each day with 5 10^{11} n/cm²s

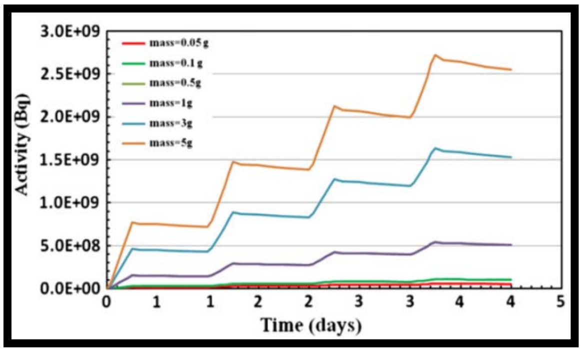

Fig. 3: Evolution of activity [35]

To validate our results we compared them with the results of *AS Elom Achorido* [35] (fig. 3). For 1g, 3g and 5g, with a neutron flux of 5 10^{11}n/cm²s, masses of TeO_2 irradiated for 6 hours** per day (fig. 2), the results show the validation of our work. In our study, we are interested in 5g, 10g, 30g, 50g, 100g and 150g.

Productions ^{131}I with 4 hours of irradiation for each cycle**

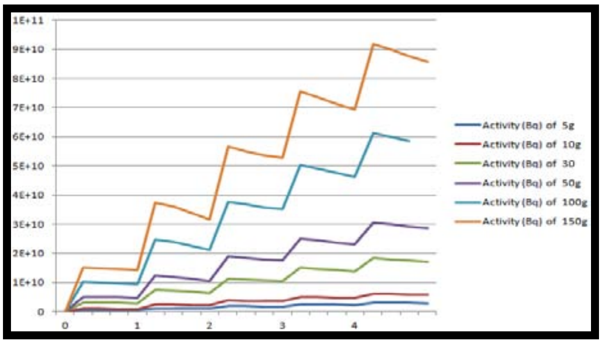

Fig. 4: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 5 10^{11} n/cm²s^{-1} for an irradiation time of 4h during each day

After four hours of irradiation by cycle, the results which are shown in fig. 4, 5, 6 and 7 clarify that the activity increases with irradiation time, then a slight decrease at the end of irradiation, then it begins to increase after the second irradiation. For example, the neutron flux of 5 10^{11}n/cm²s for masses of 5g, 10g, 50g, 100g and 150g this activity is 2.86 10^{9}, 5.72 10^{9}, 1.71 10^{10}, 2.86 10^{10}, 5.72 10^{10} and 8.57 10^{10} Becquerel respectively. if we increase the fluxes to 10^{13} n/cm²s, and for the same masses, the activity is equal to 3.80 10^{10}, 1.14 10^{11}, 3.43 10^{11}, 5.72 10^{11}, 1.14 10^{12} and 1.71 10^{12} Becquerel, respectively.

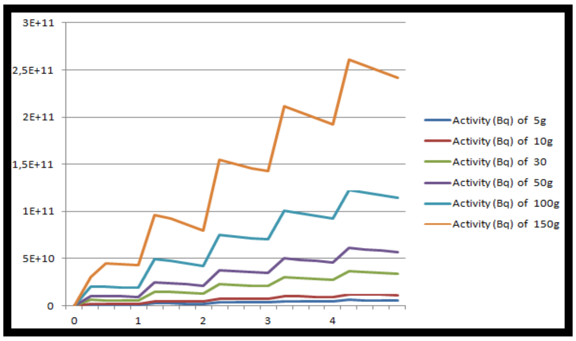

Fig. 5: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 10[12] n/cm²s-1 for an irradiation time of 4h during each day

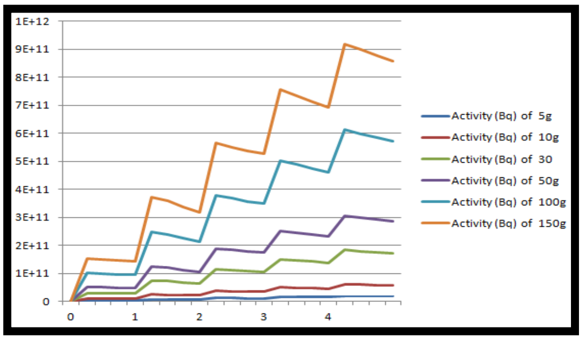

Fig. 6: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 5 10[12] n/cm²s-1 for an irradiation time of 4h during each day

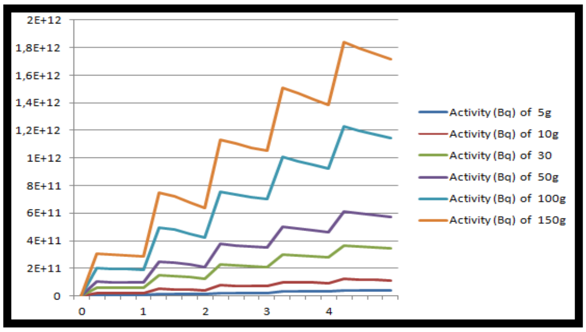

Fig. 7: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 10^{13} n/cm²s-1 for an irradiation time of 4h during each day

Productions ^{131}I with 6 hours of irradiation for each cycle**

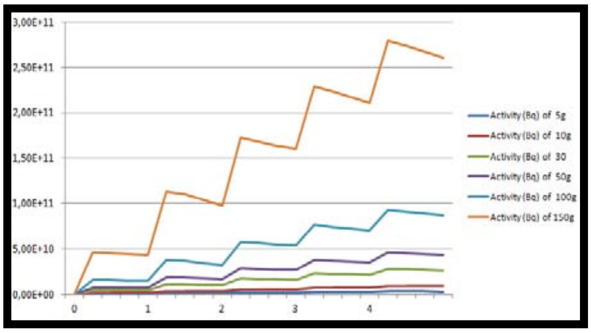

Fig. 8: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 5 10^{11} n/cm²s-1 for an irradiation time of 6h during each day

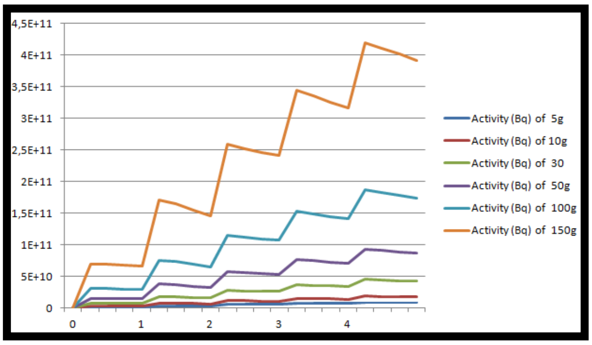

Fig. 9: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 10^{12} n/cm²s-1 for an irradiation time of 6h during each day

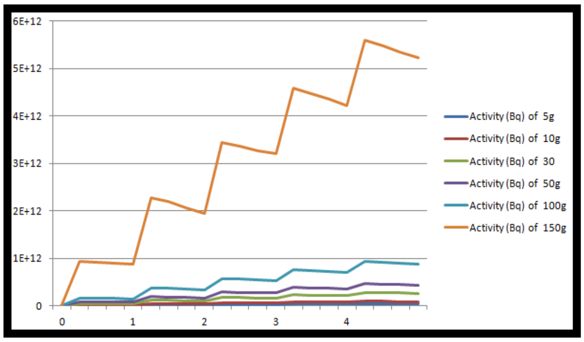

Fig. 10: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 5 10^{12} n/cm²s-1 for an irradiation time of 6h during each day

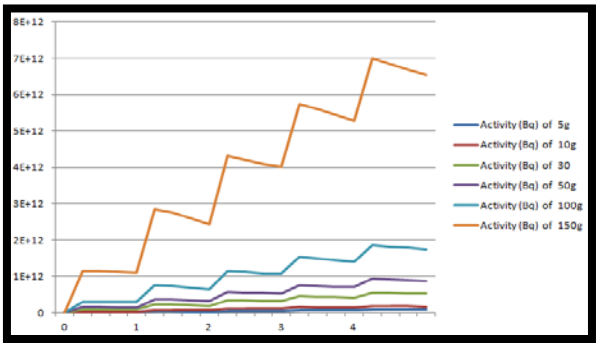

Fig. 11: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 10^{13} n/cm²s-1 for an irradiation time of 6h during each day

The schemes illustrated in fig. 8, 9, 10 and 11 explain that the activity clearly related to the level of neutron flux and the mass of samples in addition to the microscopic Cross section of target of tellurium. After the analysis of the evolution of the activity, we noticed that the activity increases every day and every increase of irradiation followed directly with a slight decrease. For example, the neutron flux of 5 10^{11}n/cm^{2}s and masses of 5g, 10g, 30g, 50g, 100g and 150g, activity was 3.08 10^9, 8.71 10^9, 2.61 10^{10}, 4.35 10^{10}, 8.71 10^{10} and 2.61 10^{11} Becquerel respectively. If we increase the flux to 10^{13} n/cm^{2}s, and for the same masses, activity equals 8.71 10^{10}, 1.74 10^{11}, 5.23 10^{11}, 8.71 10^{11}, 1.74 10^{12} and 6.53 10^{12} Becquerel, respectively.

Productions ^{131}I with 8 hours of irradiation for each cycle**

Fig. 12, 13, 14 and 15 show the evolution of ^{131}I with activation of 8 hours** per day for 5 d. The activity of iodine-131 depends on irradiation time, the neutron flux and the mass of target capsules. For example in fig. 12, the neutron flux equal to 5 10^{11} n/cm^{2}s, the activity becomes at the end of the cyclic irradiation 5.79 10^9, 1.16 10^{10}, 3.47 10^{10}, 5.79 10^{10}, 1.16 10^{10} and 1.74 10^{11} Becquerel, respectively for 5 g, 10 g, 30 g, 50 g, 100 g et 150 g. Therefore, an increase in the neutron flux to 10^{13} n/cm^{2}s and for the same masses in fig. 15, the activity increases respectively 1.16 10^{11}, 2.31 10^{11},6.94 10^{11},1.16 10^{12},2.31 10^{11} and 3.47 10^{12} Becquerel.

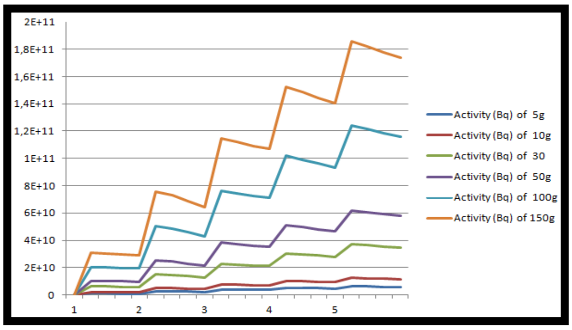

Fig. 12: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 5 10^{11} n/cm²s for an irradiation time of 8h during each day

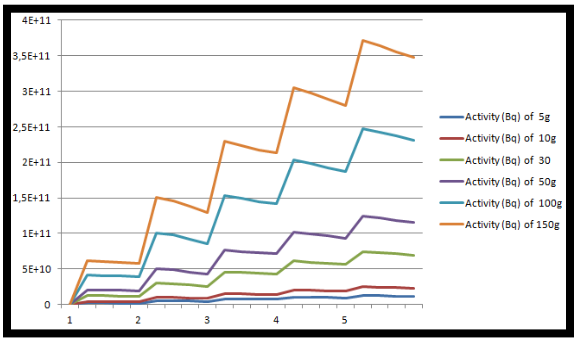

Fig. 13: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 10^{12} n/cm^{2}s^{-1} for an irradiation time of 8h during each day

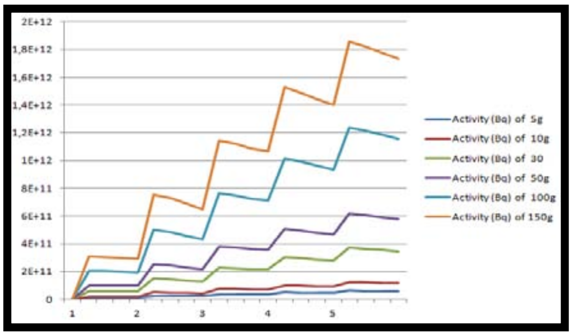

Fig. 14: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 5.10^{12}n/cm^{2}s^{-1} for an irradiation time of 8h during each day

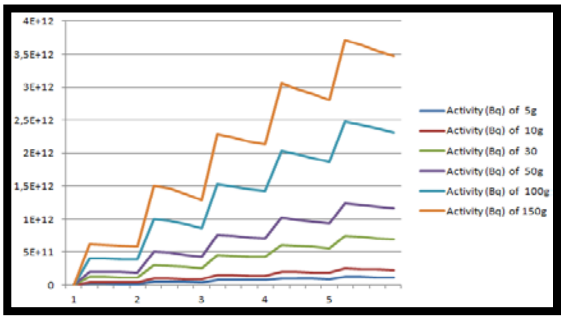

Fig. 15: Theoretical evolution activity (Bq) for I-131 production at a neutron flux of 10^{13} n/cm^{2}s^{-1} for an irradiation time of 8h during each day

Profile of activity

Maximum feasible activities have been based on the capsules used; when we increase the mass of TeO_2, it causes an increase in the activity. maximum activity in irradiation period 4, 6 and 8 hours** for the mass of 150 g give 2.317 Curie, 3.530 Curie, 4.69 Curie respectively in a flux of 5 10^{11}n/cm^{2}s, if the neutron flux increases to 10^{12} n/cm^{2}s, for the identical weight (150g) and for the same irradiation period 4, 6 and 8 hours** per day, we note that the activity increases respectively in the following values, 4.6345 Ci, 7.0616 Ci and 9.3818 Curie, fig. 16 and 17.

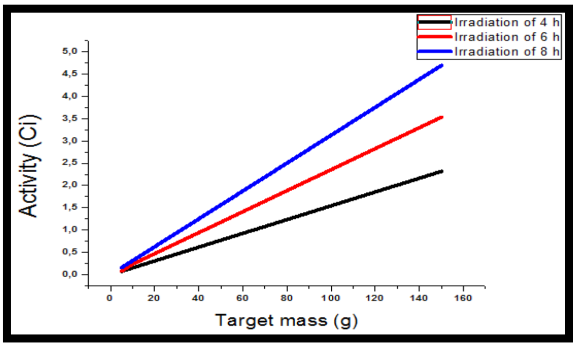

Fig. 16: Increased activity of Iodine-131 as a function of time of irradiation and the mass of the tellurium-130 target in a neutron flux of 5 10^{11} n/cm^{2}s

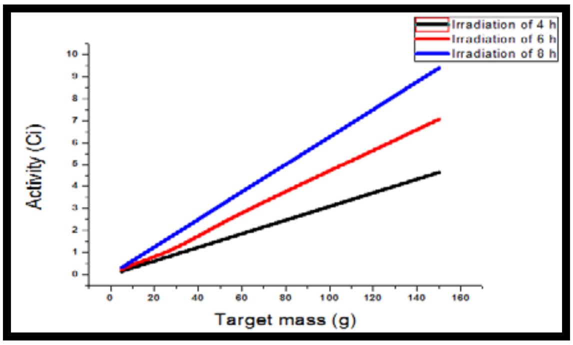

Fig. 17: Increased activity of Iodine-131 as a function of time of irradiation and the mass of the tellurium-130 target in a neutron flux of 10^{12} n/cm^{2}s

CONCLUSION

A feasibility study of the production of iodine-131 is done by using a neutron flux from 5 10^{11} to 10^{13} n/cm^2. Then the results were that the mass of 150 g and a flux of 5 10^{11} n/cm^{2}s the activity gives (2.317 Curie in 4 hours** of irradiation and 4.69 Curie in 8 hours** of irradiation), for the same mass of 160 g in a flux of 10^{12} n/cm^{2}s gives (4.634 Curie in 4 hours** of irradiation and 9.381 Curie in 8 hours** of irradiation). These results are compared with study of B. El Bekkouri [34] and AS Elom Achoribo [35]. We noticed that the neutron standpoint, an acceptable capsule for different masses of tellurium, and an irradiation in a neutron flux in the reactor, approximately in the center, can give continuation to the production of Iodine-131.

CONFLICTS OF INTERESTS

Declared none

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