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Evaluation of Iodine Transmutation Rate in the High Flux Reactor BR-2

L. Omeir* , N. Amrani, A. Boucenna

Physics department, Faculty of Sciences, Ferhat ABBAS, Setif-1, University, Setif, Algeria
Dosing, Analysis and Characterization in High Resolution Laboratory, Ferhat ABBAS, Setif-1 University, Setif, Algeria.

** Corresponding author. Cherlyes2002@yahoo.fr*

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Abstract. In this study, we evaluate the transmutation rate of the long-lived fission product Iodine to the stable Xenon under irradiation in the high flux reactor BR2. The Iodine transmutation rate and the evolution of Xenon mass under irradiation were numerically simulated using ChainSolver 2.34 code.

Keywords. Nuclear waste management, Iodine, Fission product, Transmutation.

INTRODUCTION

Iodine-129 (^{129}I) is one of the most significant long-lived fission products found in the spent nuclear fuel. The radio toxicity of ^{129}I is far below that of minor actinides, but its high mobility and relatively long life (~ 1.57 10^7 years) greatly increase the very long-term risk of storage during storage (CEA, 2006; Konings, 1997; Amrani, 2011). Iodine-129 is produced as a result of ^{235}U fission in nuclear reactors induced by thermal neutron flux. The Iodine 129 presents a major contribution to the radiological risk of the spent fuel waste in the long term (Ichimura et al., 2004).

Transmutation of ^{129}I to stable ^{130}Xe is therefore a means to reduce the radiological risk. For ^{129}I, isotopic separation not strongly required because the ^{127}I fraction is relatively small, and its capture product ^{128}I quickly decays to^{128}Xe with a half-life of 25 min. (Yang et al., 2004)

The Objectives of this study is the estimation of Iodine transmutation rate and Xenon mass obtained from iodine targets irradiated in high flux reactor BR2 considering its large capture cross section in fast and epithermal region.

IODINE TRANSMUTATION PROCESS

The scheme of Iodine transmutation and Xenon formation under neutron irradiation is presented in figure 1. The basic reaction used for transmutation of radiotoxic isotope ^{129}I in nuclear reactor is the neutron absorption. Transmutation seems to be a potential method to

achieve this since ^{129}I, can be transformed to the stable Xenon isotope ^{130}Xe by a single neutron capture (Yang, 2004).

The ^{127}I will lead to the formation of stable ^{128}Xe by capture (n, γ) and to a very small proportion of stable Tellurium ^{128}Te as following processes (Yang et al., 2004).

In our study, we consider that our target is composed of two isotopes the ^{129}I and ^{127}I. To avoid the expense of isotopic separation, the iodide target is directly formed as fission products. The Iodine composition in the targets is 82.7% ^{129}I and 17.3% ^{127}I (Xuesong et al., 2013) . The conversion of ^{127}I to ^{129}I would be very small since ^{128}I quickly decays to ^{128}Xe. As a result, both ^{127}I and ^{129}I are transmuted into stable Xenon isotopes through neutron capture reactions.

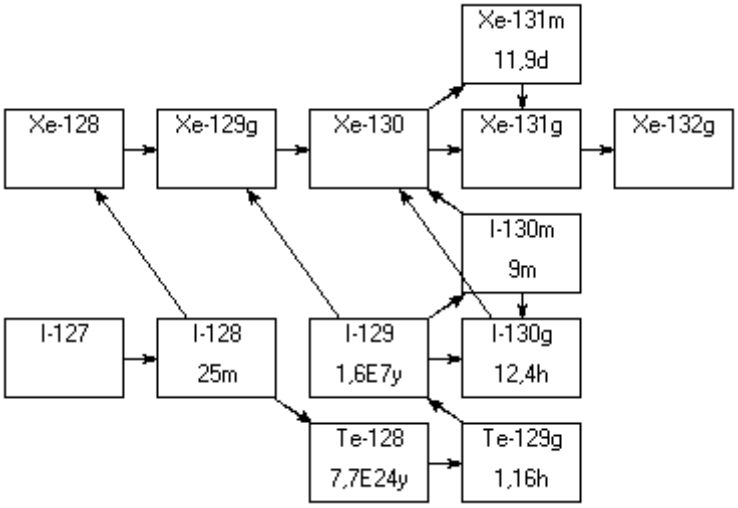

Fig. 1.The transmutation scheme of a target composed of ^{127}I and ^{129}I.

From figure 2 it can be seen that ^{129}I has a weak thermal cross section but a very large and strong resonance absorption in the epithermal energy range.

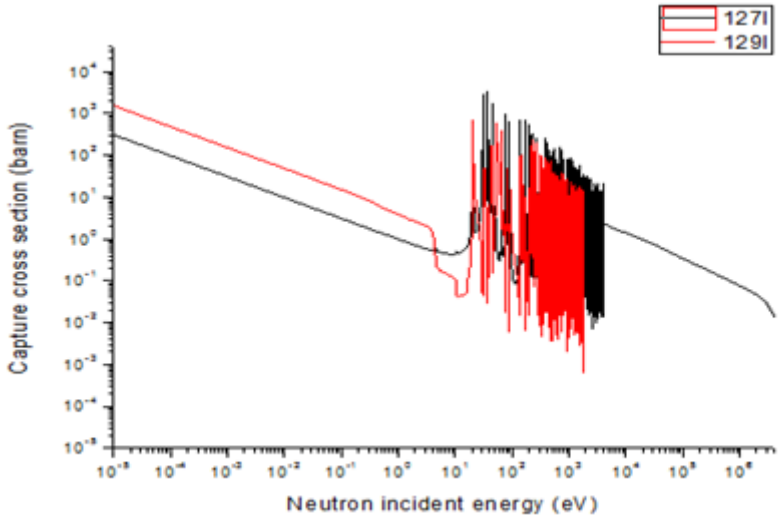

Fig. 2. Neutron capture cross section of ^{127} I and ^{129} I from ENDF library

DESCRIPTION and CHARACTERISTICS of BR2 High Flux Reactor

The BR2 reactor is a 100 MW_{th} high-flux 'materials testing reactor' witch first became operational in 1963 and has been refurbished in 1995–1997 after more than 30 years

utilization to provide a life time extension of more than 20 years (Ponsard et al., 2003). The Belgian Nuclear Research Center operates this reactor within the context of programs for the production of fission-fusion reactor structural materials and nuclear fuels.

The availability of high thermal neutron fluxes up to 10^{15} n.cm^{2}.s^{-1} offers a major potential for the regular manufacture of medical and industrial radioisotopes.

The standard irradiation cycle consists of 3–4 weeks operation at an operating power between 50 and 70 MWth. The new operating regime consists of five cycles per year of irradiation. The BR2 reactor uses enriched Uranium of 93 percent as fuel and is moderated by light water and beryllium. The core is composed of beryllium hexagons with central irradiation channels of 200, 84, 50 or 33 mm diameter. The cooling water is pressurized at 12 bars and has a temperature of 40–45 C (Figure 3). The aluminum pressure vessel is located in a pool filled with demineralized water (Ponsard et al., 2009).

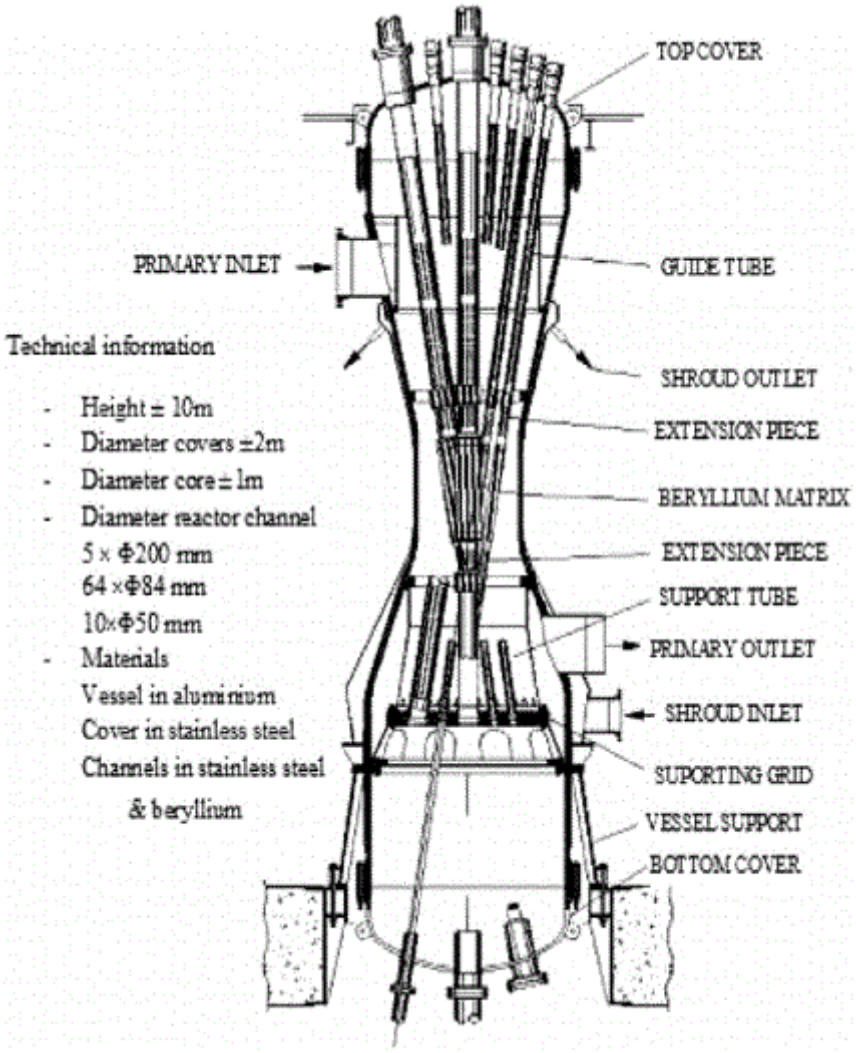

Fig. 3. BR2 High Flux Reactor.

In figure 4, the BR2 core design adopted for this study is given. 32 fuel elements, seven control rods and a regulating rod define this core configuration. These are organized around the central beryllium plug H1 in order to provide fluxes of thermal neutrons in its seven irradiation channels up to 10^{15} n.cm^{-2}.s^{-1} In peripheral reflector canals, other irradiation locations are located (Ponsard et al., 2009).

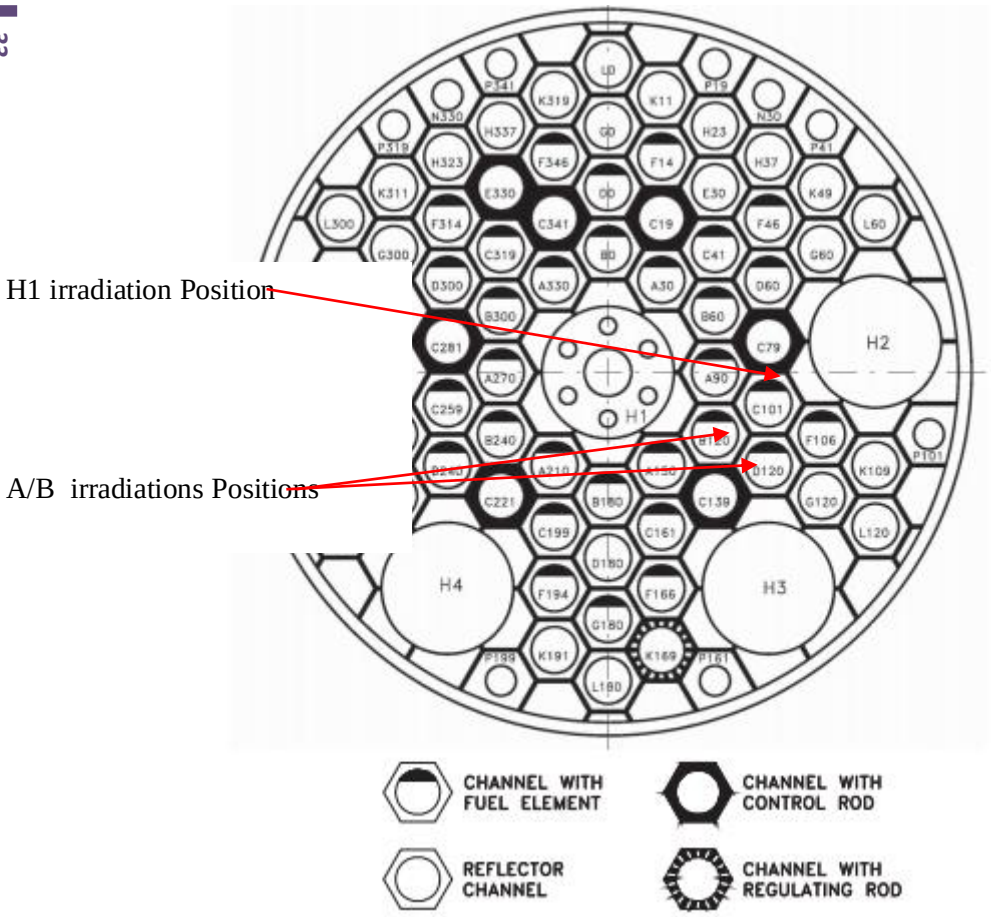

Fig. 4. BR2 Core configuration.

The considered neutron data and irradiation conditions are already given in table 1.

Table. 1. Neutron flux data (BR2 reactor).

Neutron range	BR2 (A/B)(n $cm^{-2}s^{-1}$)	BR2(H1) (n $cm^{-2}s^{-1}$)
Thermal	$2,5 \times 10^{14}$	$4,2 \times 10^{14}$
Epithermal	$3,7 \times 10^{13}$	$4,0 \times 10^{13}$
Fast > 100 keV	$5,0 \times 10^{14}$	$6,0 \times 10^{14}$

EVALUATION AND CALCULATION METHOD

The Iodine transmutation rates in the High Flux Reactor BR-2 in the central irradiation position H1 and A/B position are evaluated with ChainSolver 2.34 code used for transmutation calculations (Romanov, 2003). The ChainSolver 2.34 code is intended for fast carrying out transmutation simulation of samples during irradiation in nuclear reactors. The code calculates a nuclide density time evolution with burn-up, decay and build-up. The depression of a thermal neutrons flux, resonance self-shielding of isotopes during an irradiation, and the irradiation schedule (the schedule of the reactor work and rearrangement of an irradiated target in various positions) are taken into account. These calculations are extremely tedious because of at each stage of an irradiation the fast, epithermal and thermal fluxes, cross sections of reactions, time of an irradiation and structure of initial product should take in consideration (Krivohatskii and Romanov,1969). The main approximation used at calculation of transmutations is the assumption that the influence of changes in the irradiated material structure on characteristics of a reactor as a neutron source is insignificant.

RESULTS AND DISCUSSION

In this study, if we could operate the reactor at its maximum power, which is 100 Mwh, for a period of 310 days, two irradiation positions H1 and A/B in the BR2 reactor are adopted for an irradiation. The neutron flux data and irradiation conditions are those already given in Tab.1. The mass evolution of Xenon isotopes in both irradiation positions as a function of irradiation time obtained with Chainsolver code simulation are shown in figure 5

In the present work, numerical simulations are carried out by considering iodine samples of 150g weight, with the given isotopic composition: 82.7% of ^{129}I and 17.3% of ^{127}I.

The transmutation rate of iodine, composed of two isotopes ^{129}I and ^{127}I, obtained in both irradiation positions H1 and A/B is 22.27% and 15.61% respectively, which corresponds to a mass of 33.18 g and 23.19 g of xenon produced, composed of several isotopes.

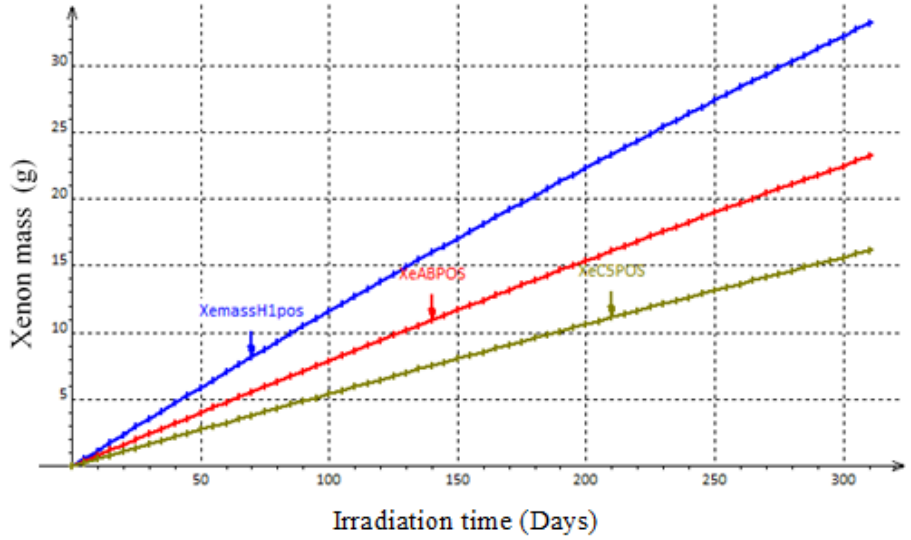

Fig. 5. The evolution of the mass of Xenon during irradiation at the H1 position (blue) and the A/B position (red) of the BR2 Reactor and C5 position of HFR Reactor during 310 days.

We notice that the transmutation rate in the H1 position is higher than in the A/B position. For comparison, the transmutation rate is calculated in the irradiation position C5 of the HFR reactor at Petten for the same values of Iodine target mass and irradiation time using in BR2 evaluation,. The flux values in the irradiation position C5 of the HFR are given in table 2 (Kloostrman and Li, 1995)

The transmutation rate in the HFR Petten high flux reactor is estimated to 10.91%.

Table 2. Flux values for the Petten high flux reactor (HFR).

HFR PETTEN	
Nominal Puissance MW_{th}	45
Fast flux	5.3×10^{14}
Thermal flux	2.0×10^{14}

It can be seen that the transmutation rates of ^{129}I obtained during irradiations values in the two irradiations positions H1 et al., A/B of BR2 reactor are greater than the obtained in irradiation position C5 of the HFR reactor at Petten.

The principal contributor in this considerable augmentation in the transmutation rate is the increase in the epithermal flux value due to its primordial role in Iodine transmutation process. This result is justified because the capture cross section of ^{129}I, are more important in the epithermal and rapid regions. Based on these results, it is estimated that reactors with high epithermal flux are more favorable for transmutation than reactors with a high flux thermal.

CONCLUSION

Like any industrial activity, the nuclear industry generates waste. The management of this waste is carried out with the objective of protecting man and the environment from the associated risks.

Most of the fission products from spent fuel are sent to a conditioning operation followed by storage. However, certain elements such as Iodine cannot be incorporated in weight quantities in conditioning matrices because of its excessive volatility.

In this study the transmutation rate of Iodine-129 in the BR2 high flux reactor is evaluated by the ChainSolver 2.34 transmutation code.

In the first simulation concerning BR2 reactor characterized by its maximum power which reaches 100Mwh, it was assumed that the targets to be irradiated with a mass of 150 g composed of 82.7% of 129I and 17.3% of the isotope 127I, are placed in the H1 position and the A/B position for a duration of 310 days.

The transmutation rate of iodine obtained at these two positions of irradiation is 22.27% and 15.61% respectively.

In the second simulation which concerns the HFR reactor characterized by a maximum power of 45 Mwh, it was assumed that these same targets with the same masses and composition, are placed at C5 position irradiation of the HFR reactor of petten for the same irradiation duration. The iodine transmutation rate obtained in this irradiation position is 10.91%.

It can be seen that the iodine transmutation rates obtained during irradiations at the two BR2 reactor positions are higher than the values obtained at the C5 irradiation position of the HFR reactor at Petten. This result is justified given that the capture cross sections of 129I are greater in the epithermal and fast regions.

Based on these results, it is estimated that reactors with high epithermal and fast epithermal flux are more favorable for transmutation than reactors with thermal flux.

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