RESEARCH PAPER | Physics | Volume : 5 | Issue : 10 | October 2015 | ISSN - 2249-555X

Calculation of fission Radioactive Products (^{85}Kr and ^{106}Ru) Generated from Ceramic fuel (UO_2) in nuclear Power Station, (PWR) Type

KEYWORDS fission products, nuclear fuel, PWR, ^{85}Kr , ^{106}Ru

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ABSTRACT *The ceramic fuel fission process within the pressurized water reactor (PWR) leads to generate radioactive fission products. The isotopes (^{85}Kr and ^{106}Ru), a money these products, which emitt gamma radiation. The process of calculations was conducted by using the computer program "MATLAB". The calculation included the effect of enrichment and neutron flux on the production ratio of these isotopes. It has been found that the increase of these parameters led to increased production of gamma-ray ratio.*

Introduction

'Nuclear reactions' those in which atomic nuclei participate-may take place spontaneously, as in radioactivity, or may be induced by bombardment with a particle or ray. Since the neutron is a neutral particle it does not experience electrostatic repulsion and can readily penetrate a target nucleus. Neutrons are thus especially useful as projectiles to induce reactions. The absorption of a neutron by most isotopes involves radiative capture, with the excitation energy appearing as a gamma ray. In certain heavy elements, notably uranium and plutonium, an alternate consequence is observed the splitting of the nucleus into two massive fragments, a process called fission [1]. Consider now a fission reaction for uranium-235 as shown in (Figure-1) From the reaction come approximately 200MeV of energy, two or three neutrons, two lighter nuclei (called fission fragments), and a number of gamma rays . The fission fragments undergo radioactive decay producing additional fission products[2]. Until they eventually become stable isotopes. After the discovery of nuclear fission process in 1939 the research continued in detail and developed scientific theories on the basis of the evolution of the structure the nucleus. Researcher "Kubota" has conducted research with his group studied, Cation-Exchange separation of Cesium-137, Strontium-90 and rare earths in nuclear fuel reprocessing waste [3]. Researchers "Hasan and Majeed" studied determination of ^{106}Ru, $^{134/137}$Cs, and ^{241}Am concentrations and action level in the imported foodstuffs consumed by inhabitants of Iraq [4]. Researcher "Blicharska " has conducted research with his group, studied separation of fission produced ^{106}Ru from simulated high level nuclear wastes for production of brachytherapy sources [5].

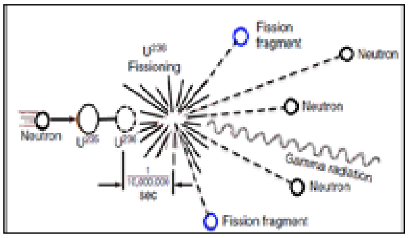

Figure (1): Scheme shows the nuclear fission process [2].

2- Theoretical part

Only one nuclear fuel occurs naturally: uranium, which contains only 0.7% of the fissionable isotope ^{235}U. The more abundant isotope ^{238}U may be converted to plutonium (^{239}Pu) by a neutron capture and decay process, and ^{239}Pu is readily fissionable. Thorium occurs abundantly and forms fissionable ^{233}U through a neutron capture and decay process (as reactions below). Hence there is one "basic" fuel uranium and two other elements thorium and plutonium which enter the fuel cycle through breeding processes.[6]

$$^{238}U + n \xrightarrow{\gamma} {}^{239}U \xrightarrow{\beta^-} {}^{239}Np \xrightarrow{\beta^-} {}^{239}Pu \qquad \text{"Uranium-plutonium cycle"}$$

$$^{232}Th + n \xrightarrow{\gamma} {}^{233}Th \xrightarrow{\beta^-} {}^{233}Pa \xrightarrow{\beta^-} {}^{233}U \qquad \text{"Thorium-uranium cycle"}$$

The fuel element is the fundamental building block of the reactor core. As it is Uranium dioxide is the most widely used fuel material in nuclear power reactors, usually in the form of cylindrical, cold-pressed, and sintered pellets with densities in the range of 92.97% of the theoretical density. The properties that combine to make UO_2 such a unique fuel material are (1) high melting point (2800°C), (2) chemical stability in water cooled reactors, (3) compatibility with cladding (Zircaloy and stainless steel), (4) excellent irradiation stability, and (5) ease of fabrication [7]. The most widely used reactor type in the world is the pressurized water reactor (PWR) as shown in (Figure-2) which uses enriched (about 3.2% ^{235}U) uranium dioxide as a fuel in zirconium alloy cans. The fuel, which is arranged in arrays of fuel "pins" and interspersed with the movable control rods, is held in a steel vessel through which water at high pressure (to suppress boiling) is pumped to act as both a coolant and a moderator. The high-pressure water is then passed through a steam generator, which raises steam in the usual way [8]

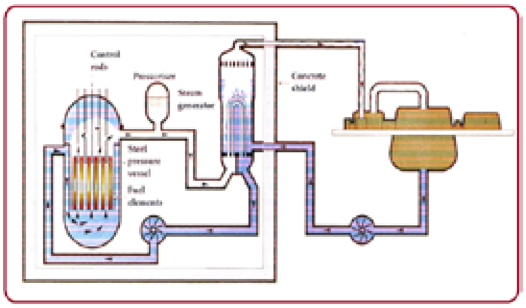

Figure (2): Scheme to pressurized water reactor [8].

3- Calculations and Results

3-1 The generation of Radioisotopes

Effect of Enrichment and Neutron Flux (y, ø): If certain material pounded with neutrons it generates radioactive isotopes by constant amount with time is calculated from the following relationship [9]

$$Q = NV.\sigma_c.\phi.Y.t \qquad (1)$$

fission Cross-Section, neutron flux, ***Y*** yield per fission accumulated during t period of the reactor operating, ***t*** Irradiation period and ***NV*** Number of nuclei of fissile nuclear fuel and it can be calculated according to the following relationship[10]

$$NV = \frac{m_{(UO_2)} \times y \times N_a}{267 \times 10^{-3}} \qquad (2)$$

$m_{(UO2)}$ is mass of fuel in the reactor core, ***y*** enrichment ratio and $\boldsymbol{N_a}$ is avogadro number (6.02

3-2 Decay of radioisotopes within the reactor

The previous calculations were based on the expense ratio of the production of the accumulated radioactive isotopes that are generated during the operation of the reactor, as it is well known that the fission products will begin to unravel after a period of operation of the reactor. The calculation can change the rate of radioactive isotopes atoms *N* after a period of operation of the reactor at the certain Neutron Flux from the following relationship [11]:

$$N = \frac{m_{(UO_2)} \times y \times N_a}{267 \times 10^{-3}} \cdot \frac{\sigma_c.\phi.Y}{\lambda}\left(1 - e^{-\lambda t}\right) \qquad (3)$$

Where λ is decay constant

Table(1): Half-life of radioactive isotopes and the yield of fission products accumulated from nuclei fission of ^{235}U [12]

Nuclide	Half-life (year)	Cumulative fission yields (%)
Kr-85	10.752	0.286
Ru-106	1.018	0.410

Table(2): Number of nuclei of fissile nuclear fuel at different enrichment ratios

Enrichment %	1.6	2.4	3.6	5
NV	3.61E+27	5.41E+27	8.12E+27	1.13E+28

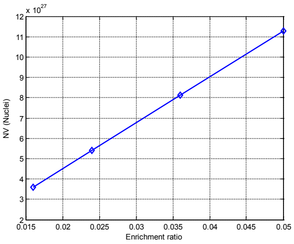

Figure (3): Effect of enrichment on the number of nuclei fissile nuclear fuel.

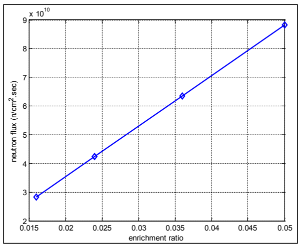

Figure (4): Effect of enrichment on the flow of neutron flux.

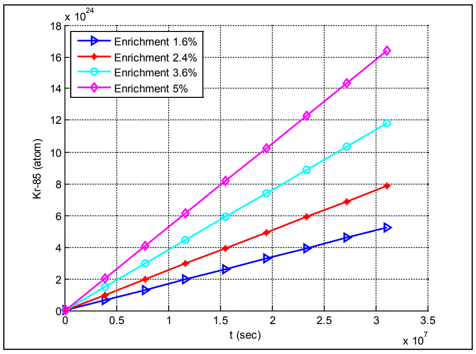

Figure (5): The production of (^{85}Kr) at different values of enrichment.

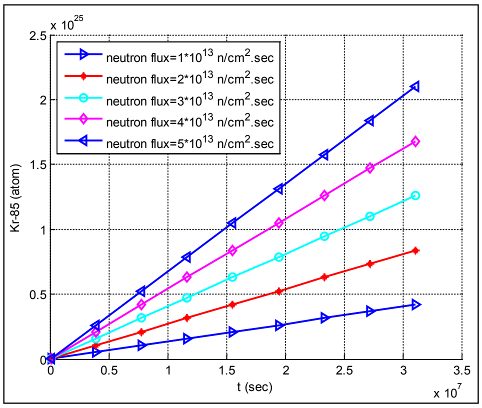

Figure (6): The production of (^{85}Kr) at different values of neutron flux.

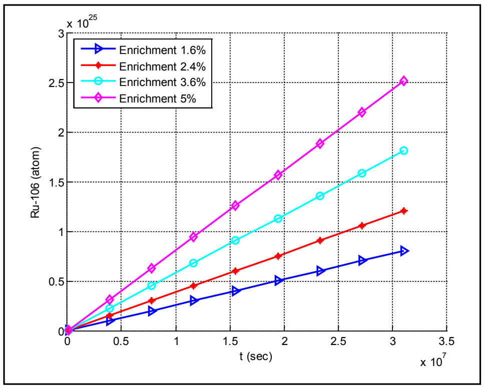

Figure (7): The production of (^{106}Ru) at different values of enrichment.

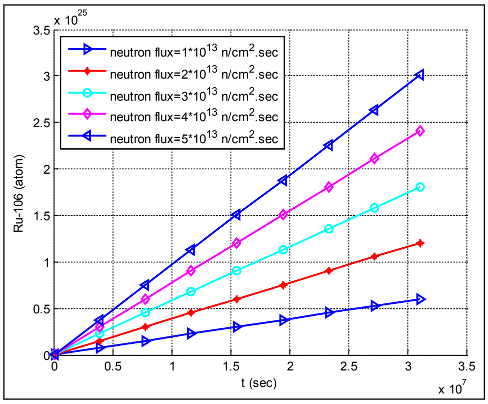

Figure (8): The production of (^{106}Ru) at different values of neutron flux.

Volume : 5 | Issue : 10 | October 2015 | ISSN - 2249-555X

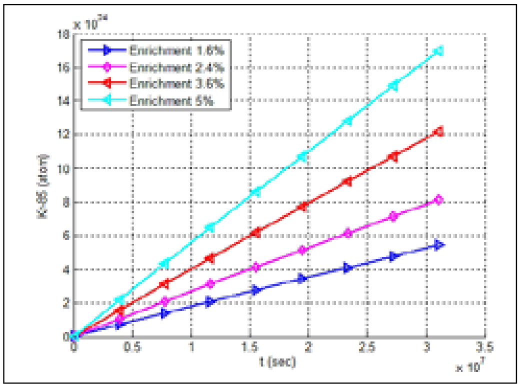

Figure (9):The accumulated number of (^{85}Kr)atoms inside the reactor because of the decay process.

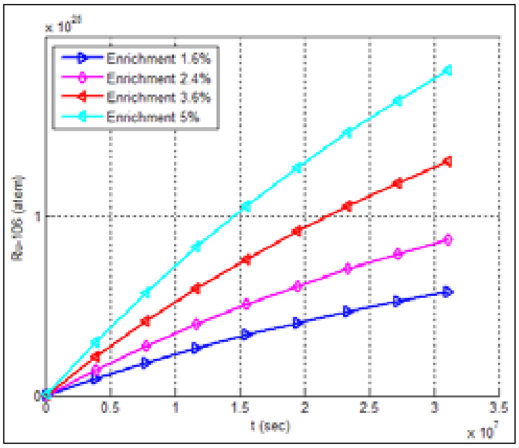

Figure (10):The accumulated number of (^{106}Ru) atoms inside the reactor because of the decay process.

4-Discussion

At increase percentage of enrichment Increasing the number of nuclei Fissile nuclear fuel as shown in figure (3) and thus lead to increase the number of neutrons generated from fission as shown in Figure (4) this leads to increased production rate of radioisotopes emitting gamma radiation as shown in figures from (5 to 8), at increase the enrichment ratio from (1-5)% increasing the production rate of (^{85}Kr) from (5.25E+24 atom) to (1.64E+25 atom) and (^{106}Ru) from (8.03E+24 atom) to (2.54E+25 atom) during the years of operation of the reactor. As well as the case of the neutron flux. The number of atoms radioisotopes generated from fission changed after a period of operation of the reactor because As shown in figures (9 and 10), noting that isotopic concentration starts to increase up to the maximum value then reach the state of equilibrium.

5-Conclusions

1- Our findings for calculating the radioactive fission products emitting gamma radiation at ceramic fuel burn-up inside pressurized water reactor compatible with experimental data.
2- Increase the enrichment ratio leads to an increased flow of neutron flux and thus increases the production ratio of radioisotopes.
3- The number of atoms generated radioisotopes gradually decreases after a short period of operation start of the reactor because of radioactive decay process.

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